AD NUMBER
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DSTL, DSIR 23/23746, 8 Dec 2008

M.A.E.E. Report No. F/Res/257

August 1955

MINISTRY OF SUPPLY

MARINE AIRCRAFT EXPERIMENTAL ESTABLISHMENT

FELIXSTOWE

INVESTIGATION OF HIGH LENGTH/BEAM RATIO SEAPLANE HULLS WITH HIGH BEAM LOADINGS

HYDRODYNAMIC STABILITY PART 21

SOME NOTES ON THE EFFECT OF WAVES ON LONGITUDINAL STABILITY CHARACTERISTICS

by

D. M. RIDLAND, A.F.R.Ae.S., G.I.Mech.E.

3/55 (A3049) Wt.61105/611. 4500. 6/55. H. E. & S. Gp.848

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S U M M A R Y

In this report the results are given of tests on three models of the series, designed to provide information on the correlation between stability with disturbance and stability in waves. No correlation was observed, but the results are analysed and compared with previous work, and some important general conclusions drawn as to the nature of disturbed stability and the behaviour of flying boats in waves.

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1. INTRODUCTION

In carrying out routine assessments of the longitudinal stability characteristics of the various models in the present research programme (References 1-20) tests were made both with and without disturbance to give a complete representation of calm water stability characteristics. As it was known that the application of disturbance impaired model stability in calm water and that full scale seaplane stability generally was adversely affected by rough seas or swells, it was thought that it might be possible to use the disturbed limits obtained in the calm water tests to assess full scale rough water characteristics. In this connection consideration has been given to the significance of the disturbed limits and a number of experiments have been made to observe model behaviour in waves. Details of these tests are given and discussed in connection with available information on disturbed limits.

The subject of wave-disturbance correlation was briefly considered in Reference 1, but most of the information given there is repeated below and discussed in conjunction with the results of further tests.

2. STABILITY WITH DISTURBANCE

2.1. Test technique

2.1.1. General

Disturbance techniques for stability testing have been used in the R.A.E. Seaplane Tank for some time. In Reference 21 (1935) it was suggested that, as calm water conditions would seldom be realised full scale, some disturbance of the water during a model test was desirable. This was achieved by doing each test run while the water surface was still disturbed from the previous run. If instability did not develop, however, the model was "disturbed fairly violently" (by hand) and the subsequent motion was observed. It was noted that sometimes the large disturbance caused instability where the smaller one (that due to the disturbed water surface) did not; on such occasions the interpretation of the results was to some extent a matter of judgment and it was found that a slightly pessimistic prediction of the full scale behaviour was often made.

A more detailed technique was necessitated by the fact that in 1938 two seaplanes, the Lerwick and the Saunders-Roe R2/33, stable model scale with the techniques then used, became unstable full scale, the latter crashing as a result of this instability. The revision of technique is reported by Gott[22] who states that "a serious difficulty appears when it is necessary to decide what is a suitable disturbance to give the model" and that "it has always been generally agreed that the model disturbance should be correctly scaled down from the maximum disturbance the full scale flying boat can receive in service. Unfortunately, individual judgment as to what this means in practice shows enormous variations and disturbances given to models have varied from a gentle touch with one finger to a push which changed the attitude of the model by perhaps 5 degrees". The apparent discrepancy between model and full scale behaviour of the Lerwick was explained when the method of applying disturbance, as well as the amount given, was found to be of fundamental importance. It was noted that a nose down disturbance was more effective in producing instability than a tail down disturbance of equal magnitude and that a train of about six waves could cause the onset of instability, quite as well as a manual disturbance, even though they were waves of small height, as long as the wave length was of the right order to produce a resonance effect ᵡ. It was

/concluded

ᵡ So-called; it is not suggested by the author of the present report that true resonance occurs, but the term being commonly used in this context it will be retained.

concluded, however, that the wave technique is too time-consuming and that a suitable manual disturbance must be given to the model: this disturbance must not be too small in case an unstable region is missed, it must not be too large, so that the aircraft under consideration is not unduly penalised, i.e. so that the aircraft under consideration is not made to appear worse than it is under normal operating conditions, and it must be of the right kind. What the right disturbance is must be determined by trial.

The disturbance in general use in 1944[23] is quoted by Smith and White in a review of porpoising phenomena, as being a severe nose down angular disturbance of the order of 10° amplitude though, in the more recent tests on the Saunders-Roe E6/44[24], the applied disturbances were of the general order of 6°-8° nose down, except at fine angles of trim, when the keel attitude was lowered to 0°, i.e. the disturbance was less than 6°. The latter is substantially the same as the method described in the most recent review of tank testing technique (Reference 25) where it is stated that "if no oscillation develops, the rear cord (model guide string) is jerked to give the model an impulsive nose down disturbance of about 6°, or sufficient to reduce the keel attitude to zero, whichever is the smaller".

It can be seen that the above techniques are not well defined and leave a great deal to the judgment of the operator, quite apart from the difficulty of applying a given degree of disturbance. While they may be satisfactory for tests on individual specific aircraft they are not suitable for tests on a research series of models; furthermore, the significance of applying a given degree of disturbance is not fully understood. The revised techniques described below were therefore used in the present investigation.

2.1.2. Present investigation

In order to obtain limits which were both reproducible and comparable from model to model, two sets of limits were obtained for each model at each weight, one being for the undisturbed case and the other for the case with maximum disturbance as defined below. The undisturbed limits indicate what can be expected full scale in very calm water without disturbance and are precise, and the test conditions are those on which the theoretical treatment is based. The disturbed limits are similarly precise and reproducible when obtained by the method used, which was

(i) to give a nose down impulsive disturbance to the model by jerking on the rear guide string, and

(ii) to give the maximum disturbance possible, so that instability was induced at all speeds and attitudes at which it was feasible to do so,

and were obtained for use in conjunction with the undisturbed limits to give a complete picture of the calm water stability characteristics.

That both sets of limits are necessary for a complete representation of calm water stability characteristics is illustrated by the comparison of limits in Figure 1 for two of the models, C and N, which were used in this programme (References 5 and 18). In the undisturbed case C appears to be the better model, but only just, whereas N is much superior under disturbed conditions. For good all-round stability N is unquestionably the better hull form, but no such clear cut decision could have been formed from a comparison of the undisturbed limits only. Alternatively, consideration of the disturbed limits only would indicate that C is far worse than N for normal operating conditions, which, of course, it is not.

/It

It was hoped that in addition to helping towards a complete understanding of calm water stability characteristics the disturbed limits could be used as an indication of rough water behaviour. Details of experiments conducted to determine whether this was in fact possible are given later in the report; the remainder of this section is concerned with disturbance limits only.

2.2. <u>The effect of disturbance on stability limits</u>

The effect of disturbance in the region unstable without disturbance is to produce a discontinuous increase in the amplitude of steady porpoising[3, 7, 11] (it follows that there must be a critical disturbance in this region, such that if it is exceeded, the model will oscillate at the higher amplitude). Further, as the degree of disturbance is increased, so is the magnitude of the unstable region until a limit is reached when no further instability can be induced regardless of the disturbance; this is referred to as the limit with maximum disturbance. Partial limits for various degrees of disturbance for Models A[3] and D[7] are shown in Figure 2 and illustrate this point; a complete set of graded limits could have been obtained, but this was considered unnecessary. It can be seen that the limit with maximum disturbance is, by its nature, a completely reproducible limit, since to render a configuration unstable it is only necessary to exceed the critical disturbance*, not reproduce it. Furthermore, it appears that a slight misjudgment of what constitutes the maximum disturbance is unlikely to be significant, as evidenced by Figure 2, where an almost correct final limit is obtained with 6^{o} of disturbance, so that the error in a limit obtained with greater amounts of disturbance should be very small.

The limits in Figure 2 are based on observations taken during normal stability tests and the marked similarity of the two diagrams may be noted. (Model D differs from Model A only with respect to afterbody length; that of Model D is one beam less than that of Model A). The number 0 indicates the limit obtained with zero disturbance and at which the amplitude of porpoising is 2^{o}; each of the other numbers indicates the limits defining unstable regions which were obtained with that number of degrees of disturbance, but the amplitude of porpoising at the limit is not necessarily 2^{o}, in fact it is generally greater. This is shown in Figure 5 of Reference 1, where the unstable regions have been divided into zones of equal steady oscillations, or in Figure 14 of Reference 3 and Figure 15 of Reference 7, where porpoising amplitudes at specific points are marked. This feature is worth noting; in the undisturbed case there is a natural gradation of amplitudes from stable to unstable regions and to talk of a 2^{o} limit infers that everywhere along the limit porpoising amplitudes of 2^{o} will be found (Figure 13, Reference 12 for instance). In the disturbed case to speak of a 2^{o} limit implies only that porpoising outside the limit is of greater amplitude than 2^{o}; amplitudes of porpoising on the limit might be of any higher value. It would be better to talk of a limit obtained with x^{o} of disturbance, or an x^{o} disturbance limit.

Examination of Figure 2 also shows that with disturbance the mid-planing region becomes unstable first, reaching a maximum width with about 5^{o} of disturbance; further increases in the degree of applied disturbance only raise the high speed lower limit. In the vicinity of the latter it has been noted that the greater the disturbance necessary to produce instability, the more violent is the resulting porpoising; in particular, following a disturbance at high speeds and low attitudes, the porpoising of every model of this series has been violent with the model leaping well clear of the water during each cycle. Again, when a hull modification is introduced which increases resistance to disturbance, this is characterised by the reduction or disappearance of disturbed instability in the mid-planing region; the high speed low attitude unstable region may be modified to some extent, but instability here appears always to be attainable if sufficient disturbance is given (References 17 and 18).

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* i.e. the minimum disturbance necessary at any particular speed and attitude to induce instability.

An investigation by Locke and Hugli[27] into disturbance effects substantiates the existence of different limits for different degrees of disturbance and of a final limit which further increases in magnitude of disturbance do not alter. This work is interesting because it was restricted to the upper limit region, where the present data are rather sparse, yet led to the same conclusions.

2.3. Mechanism of disturbed instability

So far, no mathematical theory has been advanced for the case of stability with disturbance and the phenomenon is not well understood. Gott has offered an explanation of the unstable motion following a disturbance, in terms of afterbody suctions[28]. His account is clear and, as it is generally supported by recent experience, it is repeated below.

> "Consider a model oscillating with a small amplitude, so that the motion is damped, and then let the amplitude be increased until it includes an attitude at which suction effects occur. If the suction effect is sufficiently localised it will act like an impulse applied at a particular phase in the oscillation and it is not difficult to show, from the usual expressions for a damped harmonic oscillation, that if the phase of the impulse is suitable the model will then execute a continuous undamped oscillation. ....
>
> "According to this theory the essential feature is not the disturbance required to start porpoising considered as a force or a moment, but the amplitude of oscillation required to reach an attitude at which suction effects occur. An indication of the correctness of this view was obtained on an unstable model which was made to oscillate at small steady amplitudes by running through a long and very shallow wave. Whenever the double amplitude reached about 5°, porpoising of much larger amplitude commenced. The critical condition need only be reached once and could be reached full scale due to any number of chance circumstances which do not exist at all under the controlled conditions of tank testing."

As has been seen, the existence of the critical condition referred to by Gott is confirmed by the present investigation, in which it has been referred to as the critical disturbance.

3. WAVE TESTS

3.1. Test technique

3.1.1. General

Like disturbance tests, wave tests have been made in the R.A.E. Seaplane Tank for some time and the tank apparatus seems to have undergone little, if any, modification in that time. The wavemaker is of the oscillating flap type and reproduces a deep sea wave or long swell; the waveform is approximately sinusoidal but deteriorates (i) for wave length/height ratios of about 20:1 and below, when the waves fail to reach the far end of the tank without change of form and (ii) when the wavemaker is operating under heavy loads, which give rise to illformed double-crested waves[29]. The model can only be run head on into the wavetrain, and the runs may be made with acceleration or deceleration, or at steady speeds[25].

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The general outlook with respect to tests in waves is interesting. In 1935 it was the practice to make brief tests in waves of two lengths, the shorter being about equal to the length of the hull, and the longer three times this length; the chief object of these tests was to obtain an assessment of the general seaworthiness of the hull[21]. It was considered that tests in waves merely accentuated any porpoising tendency and were not necessary (from the stability point of view) if the normal routine tests had been made. These views seem to have been generally held, where tests on specific aircraft are concerned, up to the present day. Some thorough seaworthiness tests on the Saunders-Roe E6/44 were reported in 1946, Reference 24, and in the most recent review of tank testing technique[25] most of the emphasis is on seaworthiness when waves are considered. A method is described, however, for recording the motion in pitch and heave of a model during a run through waves and reference is made to a series of tests on models of the Princess and Shetland[30] in which this method was used. These tests were very limited in scope, due probably to the time-taking nature of wave tests in general, and, apart from the present programme, they appear to be the only tests done in the R.A.E. tank with the sole object of examining aircraft stability in waves.

3.1.2. Present investigation

Apart from the generation of waves[29], and their effects, the general procedure for each of the present series of test runs was identical to that used in the corresponding calm water case without disturbance. All wave tests were made with zero flap, no slipstream, one C.G. position and at one beam loading, $C_{\Delta_0} = 2.75$; the model was towed from the wing tips on the lateral axis through the C.G. with the model free in pitch and heave, and runs were made with selected elevator settings and at constant speeds, all of which were in the planing speed range. On no occasion was the model given any manual disturbance.

Attempts were made to read the trim, as well as any change in trim, but these were not entirely successful. Sometimes the trim indicator (pointer) was steady and at other times it had a constant amplitude, high frequency vibration superimposed on the obviously steady trim indication from the model; on these occasions the motion was classed as stable. When the model oscillated in pitch a steady oscillation of greater than 2° amplitude was called unstable, but on a great number of runs the amplitude of the motion varied over the run. When this happened a certain amount of discretion was used; if, for instance, the maximum amplitude was sustained for say only two or three cycles and only this maximum value was greater than 2°, then the run was classed as stable; if it was sustained for about five or six cycles the run was termed unstable. On some runs the pitching oscillations were violent and the motion was obviously unstable. At no time, when deciding whether a motion should be called stable or unstable, was any allowance made for the motion in heave, which was occasionally very pronounced, as the main reason for doing the tests was to provide a comparison with the calm water test results, when only the motion in pitch was considered.

Having selected a speed and elevator setting the procedure adopted was to choose a wave length/height ratio and, starting with waves of small height, effectively increase the height while keeping the ratio constant until instability set in. It was found that by repeating this for several wave length/height ratios curves of definite form could be obtained (Figure 10) separating regions of stable and unstable motion; similar curves were obtained for each speed - elevator combination tested.

Critical disturbances were determined by carrying out test runs in calm water and applying disturbances, the magnitudes of which were progressively increased until instability set in.

During most of the tests only visual observations were taken because of the time otherwise involved in analysis, but recordings of a small group of runs were made, by the methods of Reference 1, for comparison with the results of Reference 30.

/3.2. Scope

3.2. Scope of tests

Wave tests were made on Models A, B and L of the series, aerodynamic and hydrodynamic data for which are given in Tables I and II respectively. As the initial aim was to determine the extent of any wave-disturbance correlation the points in the (η, V) plane examined at first were in the region between the undisturbed and disturbed stability limits; later, in the case of Model L only, the tests were extended to include points in that part of the stable region which was unaffected by disturbance. All of the points considered are numbered and listed in Table III; for convenience they will be referred to henceforth by the number and letter given in this table, e.g. 4B will indicate that Model B is being considered at a speed of 32 feet per second with elevators set at -4 degrees. The relationships between these points and the corresponding sets of stability limits are shown for each model in Figures 3 and 4, which have keel attitudes and elevator angles respectively as ordinates.

The tests on Model A were of two kinds and all were made at point 1A in the mid-planing region. In the first case a series of runs, made through waves of fixed height but of differing length/height ratios, were recorded for comparison with similar results for the Princess and Shetland. In the second case, a curve of limiting wave heights for stability was obtained on a wave length/height ratio base. In determining the points for this curve no recordings were made, the runs being classed as stable, borderline or unstable in the manner indicated in the previous paragraph. The nature of these tests was mainly exploratory and fuller tests were for convenience made on Model B.

The tests on Model B consisted of obtaining curves of limiting wave heights for stability at five points, 1B to 5B, and of determining the critical disturbance at each point. These results made it fairly clear that no detailed wave disturbance correlation would be forthcoming, though some useful general results were obtained with respect to the behaviour of the model in different wave systems. Further tests were made on Model L, but for this reason no critical disturbances were determined.

The tests on Model L were made to check the general results of Model B on a model having vastly different disturbed limits, and, in addition, wave tests were made at points in regions of the stability diagram which were completely unaffected by disturbance. Greater coverage of the (η, V) plane was made in an effort to obtain a better understanding of stability in waves and one curve, that for point 6L, was extended as far as possible within the limitations of the wavemaking system.

3.3. Discussion of results

3.3.1. Comparison of Model A with Princess and Shetland

These tests were made for comparison with similar tests on the Princess and Shetland[30], and test conditions had to be chosen accordingly. The design loading for Model A was taken as 150,000 lb., the load coefficient as 2.75 and the point selected for test, 1A, was in the mid-planing region. Test runs were made in waves 2.35 ft.* high and, in the comparison of results with the Princess, linear dimensions for Model A and the Shetland were scaled up in the ratios 2.35:3 and 2.25:3 respectively.

Six recordings were made, one for each of the wave length/height ratios 80:1 to 130:1 and they are shown in Figures 5, 6 and 7. Maximum and mean pitching and heaving amplitudes and their ratios are given in Table IV, together with corresponding results for the Princess and Shetland, which were taken from Reference 30; the amplitudes are plotted in Figure 8 and their ratios in Figure 9.

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* This figure was arrived at by scaling down the Princess wave height of 3 ft. by the cube root of the ratio of the aircraft weights, viz:-

$$\text{Wave height} = 3\left(\frac{150,000}{310,000}\right)^{1/3}$$

The most obvious feature of the Model A records generally is the apparent difference between the motions. This is probably due to the motion in each case being compounded of several basic elements the magnitude and frequency of each being proportional to different physical characteristics of the motion. In only one, that for a wave length/height ratio of 110:1, is there a regular constant amplitude motion. The 80:1 recording resembles a beat between two frequencies, the 90:1 is irregular, the 100:1 has an envelope of square waveform, while in the 120:1 and 130:1 recordings a certain tendency to regularity can be observed. It is clear that any detailed analysis of such results en masse would have to be statistical and many more recordings would be necessary, so only a rough picture can be obtained from the present set of curves.

The results are compared with those for the Princess and Shetland in Table IV where the steady speeds are speeds for the hull form concerned scaled up to the design loading and the tabulated figures are for runs through the waves of the heights indicated. When the Shetland wave height is scaled up to Princess size, so is the speed, but when Model A wave height is increased to Princess size the speed becomes 84 knots approximately, much higher than that for the Princess. To obtain the same scaled speed for Model A as for the Princess would have meant running Model A at $C_V = 5.9$, which is in the undisturbed unstable region (Figure 3). The correspondence chosen, viz: that each of the three points is representative of the mid-planing region, is considered reasonable, but the much higher speed of Model A should be borne in mind.

The mean pitching and heaving amplitudes of Figure 8 are of about the same order, as far as one can generalise, for the three hull forms, but the maximum values for Model A are greater than those for the Princess and the Shetland, particularly in the case of heave. In Figure 9 the ratios maximum amplitude:mean amplitude in both pitch and heave are seen to be greater for Model A than for the other two hulls. It should be noted that these ratios, amongst other things, constitute a measure of the irregularity of the motion, and that one large oscillation could greatly increase these values; the plots in Reference 30 were faired by hand, there being no effective damping in the recording system, and it is possible that occasional high peaks were unwittingly smoothed out. Some interesting points do arise, however, from this limited data. Resonance occurs for Model A at a wave length of 330 feet, it occurs for the Princess at 300 feet, although the curves for pitch and heave are out of phase, and it occurs for the Shetland at 270 feet (Figure 9); in each case one complete oscillation of the model corresponds to its passage through two wave crests. The greatest amplitudes of oscillation in general occur at a wave length of 330 feet for Model A, at 270 feet for the Shetland and at 270 feet for the Princess (Figure 8); the values at 300 feet for the Princess are, however, only slightly smaller than those at 270 feet. It may be said therefore that maximum amplitudes and resonance are found at the same wave lengths.

Consider now the length (from forward perpendicular to aft step) and maximum beam of each of these hulls scaled to 310,000 lb.:

Hull Form	Beam. b ft.	Length. L ft.	L/b	C_{Δ_0}	bL sq.ft.
Model A	12.05	132.6	11.0	2.75	1,600
Princess	16.66	121.0	7.3	1.08	2,010
Shetland	16.66	113.1	6.8	1.08	1,885

/If

If now the ratios of the resonant wave lengths to the respective hull lengths be determined, they are found to be almost equal, viz:

$$\text{Model A} \quad \frac{330}{132.6} = 2.5$$

$$\text{Princess} \quad \frac{300}{121.0} = 2.5$$

$$\text{Shetland} \quad \frac{270}{113.1} = 2.4$$

It would appear from this that the resonant wave length is a simple multiple of the hull length and that it is independent of hull shape or length/beam ratio.

3.3.2. The wave diagram

Before considering the remaining tests, a detailed examination of the extended wave diagram which was mentioned in Section 3.2 will make it easier to follow the subsequent discussion. The curve was obtained for point 6L (Table III) and it is given as originally plotted on a wave length/height ratio base in Figure 10. In this form it has a shape characteristic of this type of diagram but the plot on a wave length base in Figure 11 is easier to appreciate, though curves plotted in this manner have rather more varied shapes. Both figures are non-dimensional and normal stability diagram notation has been used for the stable, borderline and unstable points respectively. Maximum amplitudes of oscillation are indicated by the figures near the relevant points; if the observed motion was regular this is indicated by the underlining of the figure, otherwise the motion was irregular.

It can be seen from Figure 11 that there is a minimum wave height of 0.05 beam below which there is no instability. It may also be seen from Figure 10 that there is an upper limiting wave length/height ratio for instability; in this case the motion is stable above a ratio of about 850. There may also be a lower limiting value, but this is not indicated by the diagram. Returning to Figure 11, the motion near and below the limit at the higher wave lengths is mainly oscillatory, regular and of small amplitude, while that found at the lower wave lengths is as often irregular as regular, and the transition from steady to oscillatory motion is rather sharp. It may be noted that at these wave lengths (below 25 beams) had the limit been drawn with respect to regular motions only it would have been less severe. In general, with ingress into the unstable region, porpoising amplitudes seem to increase at first and then reach a maximum value of the order of 8 degrees; one point ($h = 0.351$ beam, $L = 35.10$ beams) is unmarked on Figure 11, but it lies well into this region and still has a maximum amplitude of only 8 degrees.

The existence of limiting values of wave length, height and length/height ratio for stability could have been expected. With regard to wave height, a wave of infinitesimal height could have no effect on the motion; it would have to reach finite size before a 2° amplitude oscillation could be induced. In the case of wave length, as this is increased at constant height the water surface approaches a plane, for practical purposes, and the motion becomes as for calm water. When the wave length is decreased, it reaches a minimum value for a given wave height, below which a stable waveform cannot exist[32]. There is thus a limiting wave length/height ratio (7) for the existence of stable waves and neither of the curves in Figure 10 or Figure 11 would therefore touch the y-axis.

The remaining results are presented in the form of Figure 11. Only the curve or limit is drawn in each case, but the points defining this curve are given in the relevant table. Lines of constant wave length/wave height ratio are shown in each figure to aid discussion and it may be

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noted that the maximum wave lengths and heights in which the general tests were made were 35 beams and 0.5 beam respectively. This gives a smaller coverage of the wave length range than in the case discussed above.

3.3.3. Model A results

The curve of limiting wave height for stability at different wave lengths is given for point 1A (see Table III and Figures 3 and 4) in Figure 12 and the points defining the curve are given in Table V. It is of similar form to that of Figure 11 when account is taken of the different vertical scales and as wave length is increased there is a progressive decrease in the wave height at which instability is met. The rate of decrease is reduced as wave length increases, until a minimum wave height for instability of the order of 0.06 beam is indicated.

The six points marked at a wave height of 0.25 beam and length/height ratios of 80 to 130 respectively are the points at which the recordings shown in Figures 5, 6 and 7 were made. Each of these recordings illustrates the type of motion which occurs at one point in the kind of diagram now being considered. It is interesting to see that the six points all lie well within the unstable region and that if there is a tendency here to a limiting porpoising amplitude as mentioned in the previous section, it was probably reached by each of the three models, Model A, Princess and Shetland, during the tests considered in Section 3.3.1.

3.3.4. Model B results

The curves of limiting wave height for stability at different wave lengths are given for points 1B to 5B (see Table III and Figures 3 and 4) in Figures 12 and 13 and the points defining the curves are given in Tables VI to X; the relevant critical disturbances are also given in these tables. The general tendency in all of these diagrams is the same as in that for Model A; as wave length is increased there is a progressive decrease in the wave height necessary to produce instability and, although the curves end rather abruptly, there is in three of the cases a definite tendency towards a minimum wave height for instability, the value of which differs from case to case. Too much attention should not be paid to the irregular shape of the curves for points 2B and 3B; the nature of the motions involved and their representation by stable or unstable points should be remembered (Section 3.1.2).

An examination of the five curves shows that in a given wave system the most stable configuration, or part of the stability diagram, is that represented by point 5B and the least stable by point 3B. If the five curves are put in order of quality with the poorest first we get 3B, 2B, 1B, 4B and 5B. 2B and 1B are at the same elevator setting (Figure 4) and indicate an improvement in stability, i.e. an increase in the wave height necessary to induce instability, with increase in speed, while 3B and 1B are at virtually the same speed and show an improvement with increase in elevator setting. Points 1B, 4B and 5B are for both progressively higher speeds and elevator settings and should, if the changes already noted are progressive and additive, show a much greater degree of improvement than the individual changes; this is in fact the case.

It may thus be tentatively concluded that stability characteristics in waves will be improved by an increase in speed or an increase in elevator setting.

3.3.5. Model L results

The curves of limiting wave height for stability at different wave lengths are given for points 1L to 14L (see Table III and Figures 3 and 4) in Figures 13 to 16 and the points defining the curves are given

/in

in Tables XI to XXIV. The general tendency for the wave height necessary for instability to be reduced as wave length is increased can still be seen in these figures, but the greater coverage of the stability diagram by the test points has resulted in a diversity of curve forms.

It is convenient to consider the curves in the following groups:

(i) 6L, 3L and 7L where $\eta = -12^\circ$,

(ii) 2L, 1L and 8L where $\eta = -8^\circ$,

(iii) 10L and 4L where $\eta = -4^\circ$ and

(iv) 12L and 13L where $\eta = 0^\circ$;

this allows the effect of increasing speed to be assessed at different elevator settings; a regrouping

(v) 6L, 1L, 10L and 14L where $C_V = 6.9$,

(vi) 8L, 4L and 12L where $C_V = 8.2$ and

(vii) 7L, 9L, 5L and 11L where $C_V = 9.2$,

allows the effect of increasing elevator setting or angle to be determined at different speeds.

The curves of the first group show, with the exception of that for 2L, that with increasing speed the wave height necessary to induce instability is increased and that the elevator setting has little bearing on this change. (It should be remembered that these remarks apply to any given wave system within the range tested and they are therefore general). The exception to this rule, point 2L, shows that much higher waves can be encountered without instability resulting than is the case at the next higher speed, point 1L. Point 2L represents the lowest speed tested, however, and is just past the hump, while the remaining points are at or above low planing speeds. The conclusion that increase in speed increases the wave height necessary for instability applies therefore only at low planing speeds and above, not at hump speeds.

The second group shows that at all speeds, as elevator angle is increased so is the wave height necessary to induce instability and, as speed is increased, so is the rate of this change.

The best configuration when planing in waves therefore is one where both speed and elevator angle are high.

3.3.6. General

From the foregoing results three general conclusions can be drawn. They apply over the range of wave systems covered in the main tests, that is in waves having wave length/height ratios of up to 200:1 or in waves of lengths which are less than that at which the minimum wave height for instability is found. The conclusions are that

(i) at any point in the planing speed range the wave height necessary to induce instability decreases with increase of wave length (probably until the resonant wave length is reached, after which it increases),

(ii) at any point in the planing speed range and at any wave length the wave height necessary to induce instability increases with increase of elevator angle, and

(iii) at any point in the range from low planing speeds upwards and at any wave length the wave height necessary to induce instability increases with increase of speed.

/Minor

Minor exceptions to these conclusions can be found, but they are not felt to be significant.

It may be noticed that here and elsewhere in the discussion points have been defined in terms of η and V not α_K and V, i.e. elevator angle has been used in preference to keel attitude. The reason is that while both are usually known accurately in calm water tests, this is not generally so in waves. When the model oscillates in pitch during wave tests it is difficult to obtain an attitude reading and when the model is reasonably steady the attitude is usually different to that obtained in calm water for the same speed and elevator setting. Observers were left with the impression that attitudes were increased by waves from their calm water values and, to check this, readings were taken at seven points, 4L, 5L, 7L, 8L, 9L, 10L and 14L (Tables XIV, XV, XVII, XVIII, XIX, XX and XXIV). When the motion was oscillatory and of small amplitude the mid-point between maximum and minimum readings (see Figure 5 for instance) was taken as the attitude for this purpose if it was not possible to obtain a steady reading before any instability built up. The mean of the readings obtained in different wave systems for each point was then plotted against the corresponding calm water attitude and the resulting curve, which is of definite form, is given in Figure 17.

It can be seen that for this particular model, L, calm water attitudes of less than 8° are increased by waves, while those greater than 8° are decreased. Maximum and minimum values of attitude apparently exist for planing in waves and in this case are 8.0° and 6.8° respectively; the mean working attitude range has thus been reduced to $1\frac{1}{4}^{\circ}$ for this model. The speeds and elevator settings at which each set of wave tests were made are indicated; speed alone does not appear to be significant, while elevator angle decreases more or less progressively with increase in attitude at each speed. The long afterbody of Model L (7 beams) has undoubtedly played a large part in fixing the changes quantitatively (the reduction of the attitude range for instance, would probably not be so great with a shorter afterbody), but it is considered that in general the calm water attitudes of all the models of this series will be similarly modified by waves.

It is interesting to examine the test results for Model L in the light of the resonant wave length found at $2\frac{1}{2}$ times the hull length with three other models. Since the hull length of Model L is 13 beams one would expect a resonant wave length of 32 beams if this ratio is to be maintained. As can be seen from Figure 11 this is consistent with the test results if a little latitude is allowed in the drawing of the wave curve. Considering the diversity of shapes represented by the four hulls concerned the agreement between the ratios resonant wave length/hull length is remarkably good and suggests that in fact there may be a general relationship involving this factor.

In Figure 17 a comparison is made of the wave stability characteristics of Models A, B and L. In the first diagram curves for the three models are compared at a mid-planing speed and medium elevator setting. The basic model (A) is the poorest, a large improvement results from forebody warp (B) and a further but lesser improvement is obtained with forebody warp and a long afterbody (L). This does not of course mean that for any given model an increase in afterbody length will be more effective than application of forebody warp in improving behaviour in waves, since it may well be that, in the instance quoted, most of the possible improvement was effected by the addition of forebody warp, leaving little scope for any further improvement by an increase in afterbody length or any other means. The improvements occur at wave lengths which are roughly equal to hull length, but near resonant wave length there is apparently little difference between the three hull forms.

The remaining diagrams show the effect of increasing afterbody length, at several speeds and elevator settings (see Table III). The first diagram of this group is for a low planing speed and shows that here the long afterbody (L) effects an enormous improvement; the remainder are for

/progressively

progressively higher speeds and indicate that while the long afterbody is slightly better in short waves it shows a progressive deterioration relative to Model B with speed at the higher wave lengths, i.e. the characteristics of the short afterbody model improve at a greater rate with increase of speed than those of the long afterbody model.

4. WAVE-DISTURBANCE CORRELATION

An attempt to correlate the effects of waves and disturbances on undisturbed calm water stability characteristics may be made in several ways and the correlation may be detailed or general. In the detailed type of correlation the critical disturbances and wave diagrams at corresponding speeds and elevator settings are compared in an attempt to obtain a point to point correspondence over the whole (η, V) plane; this can obviously be applied only to Model B results in the present case. In the general type of correlation an attempt is made to draw conclusions concerning whole areas of the (η, V) plane; Model L results are most suitable for this type of treatment by virtue of the fairly good coverage of the (η, V) plane with test points.

It should be noted that in all of the tests now under consideration the stability criterion was taken to be an oscillation in pitch of 2° amplitude and, because of the wave effect on attitude, results are expressed in terms of elevator angle, not keel attitude.

For correlation the critical disturbance, i.e. the smallest disturbance which would induce instability at any speed and elevator setting, is assumed to be equivalent to any wave system which would similarly just induce instability.

A detailed correlation may be made in the following manner. Let an x° disturbance limit be chosen (see Section 2.2); the points at which the critical disturbances are greater than x° will be stable and those at which the critical disturbances are less than x° will be unstable. If a wave system (defined by wave height h and wave length L) can be found which, by virtue of the relevant curves of critical wave heights (e.g. Figures 12 and 13), renders the points stable and unstable in exactly the same way as does the x° disturbance limit and if the procedure can be repeated with disturbance limits of various values, from one which excludes to one which includes all the points, then a detailed correlation may be said to have been established. In such a correlation the converse need not necessarily be true. The aim is to interpret disturbance limits in terms of stability in waves, not vice versa, and in the event of a detailed correlation there may remain wave systems which have no corresponding disturbance limit.

Applying this technique to Model B and choosing initially a 3.5° disturbance limit, and bearing in mind the magnitude of the critical disturbances, points 2B and 3B will be stable, points 1B and 4B will be unstable and point 5B will be borderline, i.e. the representative point will be on or near the stability limit. Turning to Figure 13 it can be seen that borderline stability will be obtained at point 5B in several wave systems having wave heights of the order of 0.2 beams. Selecting a wave system of wave height 0.2 beams and wave length 20 beams it can be seen that points 1B to 4B are rendered unstable thereby and this occurs with any system lying on the 5B curve. In this case therefore detailed correlation cannot be established. The same is true of any limit obtained with disturbances in the range 3.0 to 4.5° for Model B.

In attempting to make a general correlation no particular method was used; instead the wave curves and the calm water stability limits obtained with maximum disturbance for Model L were compared and any relevant facts were considered.

/The

The region of instability obtained with disturbance is much smaller for Model L than for Model B and, because of this, wave tests were made at points 2L, 4L, 5L and 7L to 10L, which are in the stable region which is unaffected by disturbance, in addition to points outside this region. Even at these points wave systems were encountered which could induce instability and it is clear, therefore, that at these points there can be no wave-disturbance correlation. In the previous discussion on Model B results, limits obtained with given degrees of disturbance were considered in conjunction with critical disturbances; in the case of Model L no critical disturbances were determined and the disturbed limit (Figure 4) is that for maximum disturbance. This, as can be seen from Figure 2, is probably a compound limit involving various degrees of disturbance. In a wave system which is the equivalent of this disturbed limit the previously mentioned points must be stable, points 1L, 6L, 11L, 12L and 13L must be unstable and 3L and 14L must be borderline, i.e. the representative points must lie on or near the limits. Considering the curves for points 3L and 14L in Figures 14 and 16 it can be seen that no wave system which is common to the two curves can be found. There is thus no correlation between stability characteristics in waves and the stability limit obtained with maximum disturbance.

This lack of correlation in the case of Model L is implicit in the conclusion (ii) of Section 3.3.6, which states in effect that as elevator angle is increased stability characteristics in waves are improved. As some of the high elevator angle points (11L, 12L, 13L) lie within the disturbed unstable region (Figure 4, Model L) where for any sort of correspondence a deterioration would be expected, there can be no wave-disturbance correlation.

It would appear from fundamental considerations that if any correlation were obtained, it would be purely fortuitous. From the discussion on disturbance limits (Section 2.2) it follows that there is a physical discontinuity at the limit; in going from stable to unstable regions a sudden change from steady motion to porpoising of large amplitude is obtained, whereas with the wave curves, there is a progressive increase in the amplitudes of porpoising with ingress into the unstable region and, by definition (Section 3.1.2), porpoising on the curve is of 2° amplitude.

It is clear from the foregoing that disturbance limits cannot be interpreted in terms of stability in waves.

5. DISCUSSION

It has been concluded that there is no significant relationship between stability with disturbance and stability in waves, so that information on the latter with respect to a given hull form must be obtained by carrying out tests in waves. In future tests on a dynamic model therefore, for a complete assessment of longitudinal stability characteristics, three types of stability must be investigated, viz: undisturbed and disturbed stability and stability in waves. For a satisfactory interpretation of test results the meaning of each of these types of stability should be understood and to this end a summary of the important points relating to stability with disturbance and stability in waves is given below.

When disturbance is applied the stable region obtained without disturbance is reduced and this reduction continues as the degree of disturbance is increased until a minimum region, which is unaffected by further increases in the applied disturbance, is obtained. The limit defining this region, which is known as the limit with maximum disturbance, is reproducible and is obtained by giving to the model the maximum nose-down impulsive disturbance compatible with safety. Like limits obtained with any other degree of disturbance, it marks a discontinuity in the type

/of

of motion encountered; there is a sudden change from the steady planing of the stable region to large amplitude porpoising when the limit is crossed. In general, the increase in the unstable region obtained with disturbance commences in the mid-planing region following the application of the smaller disturbances, though instability here may be prevented by a suitable hull modification, e.g. a long afterbody, and the final stages of the increase occur in the high speed, low attitude region following the application of the larger disturbances; instability can always be found in this region if large enough disturbances are applied. The violence of the porpoising following a disturbance is increased where larger disturbances are necessary to induce instability.

As disturbed limits cannot be interpreted in terms of stability in waves, but clearly represent stability characteristics with disturbance, the question of what constitutes a full scale disturbance deserves closer examination. The wash of a boat, such as that which caused the crash of the Saunders-Roe R2/33 [22], or a sudden yaw, such as that which caused porpoising and finally damage to the Solent N.J. 201 [33] are acceptable examples, but a type of disturbance which occurs regularly full scale is that encountered during landing. The suggestion that every landing constitutes a disturbance was considered in essence by Gott[31] and upheld in the light of his experience, and it was made (quite independently) in Reference 10 and supported by American evidence. It is considered therefore that limits with maximum disturbance indicate either stability characteristics in take-off or planing when a severe disturbance is encountered, or the worst stability characteristics in landing.

In waves, there is a minimum wave height and a maximum wave length/height ratio below and above which respectively no instability is obtained. The minimum wave height appears to occur at a wave length of $2\frac{1}{2}$ times the hull length; this factor of $2\frac{1}{2}$ has earlier been found to be significant with three other hull forms, the resonant wave length in each case being $2\frac{1}{2}$ times the hull length, and this may well be a universal figure. In general, it appears that at a constant planing speed and elevator setting the wave height necessary to induce instability decreases monotonically with increase of wave length until the resonant wave length is reached, and then increases. Again, the wave height necessary to induce instability at a given wave length is increased by increase of speed or elevator angle or both.

These results may be used to formulate a technique for future stability tests in waves, which can be made very brief. The worst and best wave stability characteristics will be obtained at low planing speeds with low elevator angles and at high planing speeds with high elevator angles respectively, while between these extremes there is a more or less steady change. Diagrams for these points will therefore give all the information necessary on the wave stability characteristics of a given hull in the planing speed range.

It is felt that in future tests account should be taken of motion in heave as well as that in pitch, which was the only motion of direct interest in the present investigation. During the present tests it was observed that the heaving motion occurred occasionally in the complete absence of any pitching motion, so that for any absolute assessment of the motion in waves of a given hull form the simple 2° pitch criterion is clearly inadequate; it is necessary to take account of several factors. These will include the amplitude, frequency and degree of regularity of the motion, both in pitch and heave. A suitable form of presentation for such comprehensive tests would probably be a carpet graph of amplitudes of oscillation in pitch and heave related to wave length and wave height for each elevator speed combination, with some allowance being made for the frequency of oscillation.

/Some

Some mention should be made of the lack of longitudinal freedom in the stability test rig used in the tests of the present report. This lack of longitudinal freedom has been given full theoretical consideration in the undisturbed calm water case in Reference 26, where it was concluded that variations of longitudinal velocity had only a slight effect on stability, and these conclusions were given an experimental check (Reference 21) when it was found that the model behaviour was similar under the two conditions, with and without longitudinal freedom, and that when porpoising was present the period and character of the motion taking place was unaffected by the introduction of the additional degree of freedom.

In the wave tests now under consideration most of the conclusions are based on curves or limits which were drawn with respect to porpoising of 2° amplitude. It is felt that while there will undoubtedly be an effect due to the longitudinal constraint, at these small amplitudes it will probably be negligible and at higher amplitudes it will be more quantitative than qualitative; the general conclusions of the report should in any event not be affected. The magnitude of the effect should, however, be determined if possible, together with those of the corresponding effects on the heave and forward motions, and if any of the effects is large it will obviously be necessary to arrange for longitudinal freedom in future tests.

It is possible to use the results of the present tests to suggest a method for making full scale take-offs in waves. It has been shown that greater wave heights can be encountered under conditions of maximum elevator and speed without inducing instability than otherwise, so the best course is to keep the control column forward and increase speed as quickly as possible. This implies that the effect of acceleration is (a) not detrimental and (b) roughly constant over the (η, V) plane. In the present wave tests instability was damped out while running up to speed and, as in the calm water case (in which acceleration is beneficial) it has not been considered worthwhile in the light of experience to check the constancy of the effects of acceleration on stability over the (η, V) plane, these points can, for the present, be neglected.

While keeping the stick forward during take-off undue concern about the nose of the aircraft digging in or being sucked down need not be felt. The indication of a minimum mean attitude in Section 3.3.6 suggests that in fact the opposite will happen; the pilot will have to hold his aircraft down and allow it to become airborne when flying speed is reached.

Perhaps the most enlightening conclusion bearing on take-offs in waves is that the resonant wave length is $2\frac{1}{2}$ times the hull length; during take-off waves of this length should be avoided by as much as possible. Waves of just less than resonant length and above, may be effectively lengthened by following a take-off path as near parallel to the waves as possible, when there will be little risk of instability, but application of this technique in shorter wave lengths may cause resonance and is therefore dangerous; in short waves take-offs should be made head on into the waves. The pilot can decide on which course to follow after making or obtaining an estimate of the wave length relative to the length of his aircraft.

An analogous technique could be devised for landing and would need only a suitable allowance for deceleration effects.

/LIST OF SYMBOLS

LIST OF SYMBOLS

b	beam of model
C_L	lift coefficient = $L/\frac{1}{2}\rho sV^2$ (L = lift, ρ = air density)
C_V	velocity coefficient = $V/\sqrt{gb}$
C_Δ	load coefficient = Δ/wb^3 (Δ = load on water and w = weight per unit volume of water)
$C_{\Delta o}$	load coefficient at $V = 0$
C_X	longitudinal spray coefficient = x/b
C_Y	lateral spray coefficient = y/b
C_Z	vertical spray coefficient = z/b
	{(x, y, z) co-ordinates of points on spray envelope relative to axes through step point}
S	gross wing area
V	velocity
α_K	keel attitude
η	elevator setting
h	wave height
L	wave length

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/TABLE I

TABLE I

MODEL AERODYNAMIC DATA

Mainplane	
Section	Gottingen 436 (mod.)
Gross area	6.85 sq. ft.
Span	6.27 ft.
S. M. C.	1.09 ft.
Aspect ratio	5.75
Dihedral (on 30% spar axis)	3° 0'
Sweepback (on 30% spar axis)	4° 0'
Wing setting (root chord to hull datum)	6° 9'
Tailplane	
Section	R. A. F. 30 (mod.)
Gross area	1.33 sq. ft.
Span	2.16 ft.
Total elevator area	0.72 sq. ft.
Tailplane setting (root chord to hull datum)	2° 0'
Fin	
Section	R. A. F. 30
Gross area	0.80 sq. ft.
Height	1.14 ft.
General	
* C. G. position	
distance forward of step point	0.237 ft.
distance above step point	0.731 ft.
* $\frac{1}{4}$ chord point S. M. C.	
distance forward of step point	0.277 ft.
distance above step point	1.015 ft.
* Tail arm l (C. G. to hinge axis)	3.1 ft.
* Height of tailplane root chord L. E. above hull crown	0.72 ft.

* These distances are measured either parallel to or normal to the hull datum.

/TABLE II

TABLE II

MODEL HYDRODYNAMIC DATA

Model	A	B	L
Beam at step	0.475'	0.475'	0.475'
Length of forebody	6b	6b	6b
Length of afterbody	5b	5b	7b
Forebody warp (per beam)	0°	4°	4°
Angle between forebody and afterbody keels	6°	6°	6°
Forebody deadrise at step	25°	25°	25°
Afterbody deadrise	30°	30°	30°
Step depth	0.15b	0.15b	0.15b
Step form	Unfaired transverse		
Pitching moment of inertia (lb. ft.^{2})	22.9	21.3	25.5

/TABLE III

TABLE III

TEST POINTS FOR WAVE TESTS

Point	Model	Speed	Cv	Elevator Setting
		ft./sec.		degrees
1	A, B, L	ж 28	7.2	- 8
2	B, L	24	6.1	- 8
3	B, L	29	7.4	-12
4	B, L	32	8.2	- 4
5	B, L	36	9.2	- 2
6	L	27	6.9	-12
7	L	36	9.2	-12
8	L	32	8.2	- 8
9	L	36	9.2	- 6
10	L	27	6.9	- 4
11	L	36	9.2	- 1
12	L	33	8.4	0
13	L	37	9.5	0
14	L	27	6.9	+ 4

ж This speed should be 27 ft./sec. for Model L.

Note: The point number and model letter are used to identify the test points, e.g. 3L will indicate Model L at 29 ft./sec. with elevators set at -12°.

/TABLE IV

TABLE IV

TEST DATA FOR RECORDED STEADY SPEED RUNS

Wave Length/Ht. Ratio	Maximum Pitching Amplitude	Mean Pitching Amplitude	Maximum Amplitude in Heave	Mean Amplitude in Heave	$\frac{\text{Max. Pitch}}{\text{Mean Pitch}}$	$\frac{\text{Max. Heave}}{\text{Mean Heave}}$
	(degrees)	(degrees)	(feet)	(feet)		
MODEL A. Steady speed 74 knots. Wave height 2.35 ft.						
80:1	12.0	5.5	13.0	5.0	2.18	2.60
90:1	15.0	9.0	17.0	10.0	1.66	1.70
100:1	14.0	8.0	15.0	8.5	1.75	1.76
110:1	14.0	12.0	15.5	13.0	1.17	1.20
120:1	12.0	8.5	11.0	7.0	1.41	1.57
130:1	7.5	4.5	5.5	3.0	1.67	1.83
PRINCESS. Steady speed 69 knots. Wave height 3.0 ft.						
80:1	11.1	8.3	12.8	9.4	1.34	1.36
90:1	12.6	9.3	16.3	12.3	1.35	1.33
100:1	10.7	8.5	16.1	11.1	1.26	1.45
110:1	10.0	7.2	17.3	10.4	1.39	1.66
130:1	12.1	8.3	20.8	12.8	1.45	1.63
SHETLAND. Steady speed 59 knots. Wave height 2.25 ft.						
80:1	12.5	11.5	9.7	9.0	1.09	1.08
90:1	14.8	13.6	12.8	11.8	1.09	1.08
100:1	6.6	4.0	5.2	2.9	1.64	1.79
110:1	7.6	5.7	4.7	3.2	1.34	1.47
120:1	7.9	6.5	5.4	4.1	1.22	1.31
130:1	10.1	6.7	7.0	5.1	1.49	1.38

	Assumed design loading	C_{Δ_o}
Model A	150,000 lb.	2.75
Princess	310,000 lb.	1.08
Shetland	131,000 lb.	1.08

/TABLE V

TABLE V

WAVE TEST DATA FOR MODEL A

Point 1A. $C_{\Delta_o} = 2.75$, $C_V = 7.2$, $\eta = -8^o$

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.033	11.66	0.070	24.50	350	1.53	US		
0.008	1.67	0.019	3.50	200	0.56	S		
0.017	3.33	0.035	7.01	200	0.80	S		
0.025	5.00	0.053	10.53	200	0.98	S		A judder corresponding to impact on each wave front was noticeable.
0.033	6.66	0.070	14.02	200	1.14	S		Slight oscillation in height similar to previous run, but the model appeared to cut through the waves.
0.042	8.34	0.087	17.58	200	1.28	US		Constant amplitude about 9°. Run not quite long enough to check.
0.033	5.00	0.070	10.53	150	0.99	S		No change in attitude whatsoever - just rode the waves.
0.042	6.25	0.087	13.17	150	1.10	US	3	
0.042	6.25	0.087	13.17	150	1.10			Repeat run. Amplitude built up slowly at first, then at increasing speed reaching 12° approximately at the end of the run.
0.033	3.33	0.070	7.01	100	0.80	S		No change in height or attitude - cut through the waves.
0.042	4.17	0.087	8.78	100	0.90	B		Just becoming unstable at end of run - took a very long time to build up.
0.042	4.17	0.087	8.78	100	0.90	B		Repeat run. Model just became disturbed at end of run, although put in early. The motion was somewhat irregular reaching an amplitude of about 3° before carriage stopped.
0.050	5.00	0.105	10.53	100	0.99	US		Still not a quick build-up. An amplitude of about 10° reached at the end of the run.
0.042	2.09	0.087	4.39	50	0.62	S		No sign of change in height or attitude. Cut through the waves.
0.050	2.50	0.105	5.26	50	0.69	S		No height or attitude change. Boat cutting through waves.
0.058	2.92	0.123	6.14	50	0.74	S		No sign of change in attitude or height.
0.067	3.33	0.140	7.01	50	0.80	S		No change in height or attitude.
0.075	3.75	0.158	7.89	50	0.85	US		Reached an amplitude of 12°-13°.
0.058	4.09	0.123	8.62	70	0.89	B	2	Damped out in middle of run and started again.
0.067	4.67	0.140	9.83	70	0.95	US		Reaching 10° amplitude at end of run - still taking whole run to build up.
0.092	2.75	0.193	5.79	30	0.72	S		No change in height or attitude.
0.100	3.00	0.210	6.31	30	0.76	B	2.5	Damped out and built up again at end of run - confused.
0.108	3.25	0.228	6.84	30	0.78	US		Wave system slightly irregular. Amplitude about 10° at end of run.

/TABLE VI

TABLE VI

WAVE TEST DATA FOR MODEL B

Point 1B. $C_{\Delta_o} = 2.75$, $C_V = 7.2$, $\eta = -8^o$. Critical disturbance = 3.0^o.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.033	6.67	0.070	14.04	200	1.14	S		
0.042	8.34	0.087	17.54	200	1.28	US		
0.042	6.25	0.087	13.15	150	1.10	B		Just under 2^o amplitude.
0.050	7.50	0.105	15.80	125	1.21	US		
0.062	5.00	0.132	10.50	80	1.00	B		Just under 2^o amplitude.
0.092	4.58	0.193	9.65	50	0.94	US		
0.083	4.17	0.175	8.77	50	0.90	US		
0.075	3.75	0.158	7.90	50	0.85	B		
0.083	2.50	0.175	5.26	30	0.68	B		Just under 2^o amplitude.
0.083	2.75	0.175	5.79	33	0.72	S		
0.092	3.00	0.193	6.31	33	0.75	S		
0.100	3.00	0.211	6.31	30	0.75	US		

TABLE VII

WAVE TEST DATA FOR MODEL B

Point 2B. $C_{\Delta_o} = 2.75$, $C_V = 6.1$, $\eta = -8^o$. Critical disturbance = 4.0^o.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.033	6.67	0.070	14.04	200	1.14	S		
0.042	8.34	0.087	17.54	200	1.28	US		
0.042	6.25	0.087	13.15	150	1.10	US		
0.100	3.00	0.211	6.31	30	0.75	US		
0.083	2.50	0.175	5.26	30	0.68	B		
0.075	2.25	0.158	4.74	30	0.65	S		
0.062	3.33	0.132	7.01	53	0.80	S		
0.067	3.33	0.140	7.01	50	0.80	B		Just under 2^o amplitude.
0.075	3.75	0.158	7.90	50	0.85	B		
0.058	4.08	0.123	8.60	70	0.89	S		
0.062	4.67	0.132	9.83	75	0.95	S		
0.071	4.96	0.149	10.43	70	0.98	US		
0.058	5.00	0.123	10.50	86	0.99	S		
0.058	5.83	0.123	12.27	100	0.99	US		
0.044	5.21	0.092	10.96	119	1.01	B		Just under 2^o amplitude.

/TABLE VIII

TABLE VIII

WAVE TEST DATA FOR MODEL B

Point 3B. C_{Δ_o} = 2.75, C_V = 7.4, η = -12°. Critical disturbance = 4.5°.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.025	5.00	0.053	10.50	200	0.98	S		
0.033	6.67	0.070	14.04	200	1.14	US		
0.042	8.34	0.087	17.54	200	1.28	US		
0.050	10.00	0.105	21.05	200	1.42	US		
0.033	5.00	0.070	10.50	150	0.99	S		
0.042	6.25	0.087	13.15	150	1.10	US		
0.100	3.00	0.211	6.31	30	0.75	US		
0.083	2.50	0.175	5.26	30	0.68	B		
0.075	2.25	0.158	4.74	30	0.65	S		
0.062	3.33	0.132	7.01	53	0.80	B		
0.058	2.91	0.123	6.13	50	0.74	S		
0.058	5.00	0.123	10.50	86	0.99	B		
0.050	5.00	0.105	10.50	100	0.99	S		

TABLE IX

WAVE TEST DATA FOR MODEL B

Point 4B. C_{Δ_o} = 2.75, C_V = 8.2, η = -4°. Critical disturbance = 3.0°.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.042	8.34	0.087	17.54	200	1.28	S		
0.050	10.00	0.105	21.05	200	1.42	S		
0.058	11.66	0.123	24.55	200	1.53	US		
0.058	8.75	0.123	18.42	150	1.32	B		
0.100	3.00	0.211	6.31	30	0.75	S		
0.108	3.25	0.228	6.84	30	0.78	S		
0.117	3.50	0.246	7.36	30	0.82	S		
0.142	3.75	0.298	7.90	26	0.85	S		
0.100	5.00	0.211	10.50	50	0.98	S		
0.117	5.83	0.246	12.27	50	1.07	US		
0.100	7.00	0.211	14.73	70	1.17	US		
0.092	6.41	0.193	13.50	70	1.12	S		
0.075	7.50	0.158	15.80	100	1.21	US		
0.067	6.67	0.140	14.04	100	1.14	S		
0.108	5.41	0.228	11.39	50	1.03	S		

/TABLE X

TABLE X

WAVE TEST DATA FOR MODEL B

Point 5B. $C_{\Delta_0} = 2.75$, $C_V = 9.2$, $\eta = -2^\circ$. Critical disturbance = 3.5°.

h ft.	L ft.	h b	L b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.042	8.34	0.087	17.54	200	1.28	S		
0.050	10.00	0.105	21.05	200	1.42	S		
0.058	11.66	0.123	24.55	200	1.53	S		
0.100	17.50	0.211	36.80	175	1.98	US		
0.108	13.60	0.228	28.65	125	1.68	US		
0.100	12.50	0.211	26.30	125	1.60	US		
0.092	6.67	0.193	14.04	73	1.14	S		
0.108	7.59	0.228	16.00	70	1.22	US		
0.092	5.00	0.193	10.50	55	1.00	S		
0.100	5.00	0.211	10.50	50	1.00	S		
0.108	5.40	0.228	11.36	50	1.03	S		
0.100	9.00	0.211	18.95	90	1.34	S		
0.096	14.40	0.202	30.30	150	1.74	US		
0.092	18.33	0.193	38.60	200	2.05	US		Just over 2° amplitude.
0.083	15.00	0.175	31.60	180	1.78	S		
0.092	11.45	0.193	24.10	125	1.52	B		Just below 2° amplitude.
0.108	3.50	0.228	7.36	32	0.83	S		
0.125	3.50	0.263	7.36	28	0.83	S		
0.117	5.83	0.246	12.27	50	1.07	S		
0.125	6.25	0.263	13.15	50	1.10	S		

TABLE XI

WAVE TEST DATA FOR MODEL L

Point 1L. $C_{\Delta_0} = 2.75$, $C_V = 6.9$, $\eta = -8^\circ$.

h ft.	L ft.	h b	L b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.033	5.00	0.070	10.50	150	0.99	S		
0.058	7.50	0.123	15.80	129	1.22	US	4.5	Not periodic.
0.050	7.50	0.105	15.80	150	1.22	US	4	Irregular.
0.042	6.25	0.087	13.15	150	1.10	B	1	Irregular.
0.071	5.00	0.149	10.51	71	0.99	B		Nearer a periodic oscillation of 1.5°.
0.112	5.85	0.237	12.30	52	1.07	US	7	Periodic.
0.079	5.85	0.167	12.30	74	1.07	US	7	Two step porpoising.
0.087	4.80	0.184	10.10	55	0.97	US	4	Nearly regular.
0.067	3.85	0.140	8.10	58	0.86	S		
0.067	5.00	0.140	10.51	75	0.99	S		
0.050	5.00	0.105	10.51	100	0.99	S		
0.067	6.66	0.140	14.00	100	1.14	US	2.5	Periodic, "jerky" type of motion.
0.117	4.65	0.246	9.79	40	0.95	US	5	Periodic.
0.092	4.00	0.193	8.41	44	0.88	US	4	Periodic.
0.083	3.35	0.175	7.05	40	0.80	US	2.5	Periodic.
0.067	2.65	0.140	5.58	40	0.70	S		
0.100	3.00	0.211	6,31	30	0.75	US	2	Steady, interspersed with 3°.
0.033	6.65	0.070	14.00	200	1.14	S		
0.033	8.35	0.070	17.57	250	1.28	S		Steady except for one swing of 1.5°.
0.042	8.30	0.087	17.47	200	1.28	B		Steady except for occasional "flicker" of 1°.
0.046	10.00	0.097	21.05	218	1.42	US	4.5	
0.042	10.40	0.087	21.90	250	1.45	US		Periodic "kicks" of 5°.

/TABLE XII

TABLE XII

WAVE TEST DATA FOR MODEL L

Point 2L. $C_{\Delta_o} = 2.75$, $C_V = 6.1$, $\eta = -8^o$.

h ft.	L ft.	h b	L b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.067	13.35	0.140	28.10	200	1.66	US	4	Follows wave frequency.
0.108	8.00	0.228	16.83	74	1.25	US	2.5	Divergent - convergent.
0.033	8.00	0.070	16.83	240	1.25	B	1.5	Periodic.
0.058	8.35	0.123	17.57	143	1.28	S	1	Built up erratically to 1.8^o then down to 1.5^o.
0.042	8.35	0.087	17.57	200	1.28	S	1.2	Erratic motion, amplitude 0.9^o.
0.092	8.35	0.193	17.57	91	1.28	US	6.5	Steady. Before porpoising built up, wake cross-sections just off step widened and narrowed alternately - apparently at same frequency as waves met hull. When unstable, afterbody was wetted for a max. of 1b and then completely clear.
0.071	6.65	0.149	14.00	94	1.14	S		Steady except for slight oscillation. Wake section fluctuation, almost allowed wake to touch afterbody above chine.
0.054	10.70	0.114	22.50	197	1.47	S	1.5	Erratic. Wetting of afterbody from 1.5b to 0 but rarely completely clear.
0.075	12.00	0.158	25.26	160	1.56	US	2.7	Fairly steady. Wake nearly touched afterbody wall, and afterbody alternately clear and wetted up to max. 1.5b, mean 1b.
0.075	9.00	0.158	18.95	120	1.34	S	6.7 to 8	At start fairly steady, built up erratically. Afterbody wetting initially between 1.0 and 0.1b finally between 1.5b and clear.
0.083	6.65	0.175	14.00	80	1.14	S		Steady afterbody planing area starting at 1.5b and running off end - in phase with similar movement on forebody - obviously of same period as waves.
0.130	7.50	0.272	15.80	58	1.22	S	<0.4	Steady. Motion as for previous run. Heavy vertical oscillation.
0.240	7.35	0.509	15.46	30	1.20	S		Steady in pitch. Large oscillation in heave.
0.175	9.70	0.368	20.40	55	1.39	US	2.2	Large oscillation in heave.
0.225	9.70	0.474	20.40	43	1.39	US	5	Fairly large oscillation in heave.
0.208	8.80	0.439	18.50	42	1.32	US	5.5	Originally stable and built up slowly.
0.175	7.70	0.368	16.20	44	1.23	S		Ragged movement in pitch over 1^o.
0.240	8.70	0.509	18.30	36	1.32	US	3.5	Fairly large oscillation in heave Motion in general seems to start with oscillation in heave while pitching motion builds up slowly, starting from zero.
0.058	14.00	0.123	29.46	240	1.71	US	4.0	

/TABLE XIII

TABLE XIII

WAVE TEST DATA FOR MODEL L

Point 3L. $C_{\Delta_0} = 2.75$, $C_V = 7.4$, $\tau = -12^o$.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.033	5.00	0.070	10.50	150	0.99	S		
0.058	7.50	0.123	15.80	130	1.22	US	5	Not periodic.
0.050	7.50	0.105	15.80	150	1.22	US	3.5	Irregular.
0.042	6.25	0.087	13.15	150	1.10	US	5	Irregular.
0.071	5.00	0.149	10.51	70	0.99	B	2	Irregular.
0.113	5.85	0.237	12.30	52	1.07	US		Approaching periodic oscillation of 6^o.
0.079	5.85	0.167	12.30	74	1.07	US		Approaching periodic motion of 4.5^o.
0.087	4.80	0.184	10.10	55	0.97	US	5.5	Steady. Two step porpoising.
0.067	3.85	0.140	8.10	57	0.86	US	4.5	Nearly steady.
0.058	4.10	0.123	8.63	70	0.89	US	2.5	Erratic.
0.050	5.00	0.105	10.51	100	0.99	B	0.4	Slight oscillation.
0.067	6.66	0.140	14.00	100	1.14	US	3.5	Irregular.
0.058	2.75	0.123	5.79	47	0.72	S		
0.071	3.75	0.149	7.90	53	0.85	B	1.5	Steady.
0.046	2.90	0.097	6.10	63	0.74	S		
0.042	5.00	0.087	10.51	120	0.98	S		
0.058	5.00	0.123	10.51	86	0.98	US		Repeatedly built up to 2.5^o then damped out.
0.050	3.80	0.105	8.00	76	0.85	S		
0.058	4.45	0.123	9.36	76	0.92	US	2.5	Periodic.
0.117	4.65	0.246	9.79	40	0.95	US	9	Two step porpoising.
0.092	4.00	0.193	8.41	43	0.88	US	4	Periodic.
0.083	3.35	0.175	7.05	40	0.80	US	4	
0.067	2.65	0.140	5.58	40	0.70	S		
0.083	2.50	0.175	5.26	30	0.69	B	1	Steady.
0.100	3.00	0.211	6.31	30	0.75	US	4	Steady.
0.033	6.65	0.070	14.00	200	1.14	B		Small. Periodic increase to 1.5^o.
0.033	8.35	0.070	17.57	250	1.28	US	3	Steady.
0.042	8.30	0.087	17.47	200	1.28	US	2.5	Steady.
0.025	6.25	0.053	13.15	250	1.10	S		

/TABLE XIV

TABLE XIV

WAVE TEST DATA FOR MODEL L

Point 4L. $C_{\Delta_o} = 2.75$, $C_V = 8.2$, $\eta = -4^o$.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Attitude degs.	Max. Amp. degs.	Remarks
0.033	8.00	0.070	16.83	240	1.25	US			Fairly steady with occasional "flicks" ≫ 2°.
0.167	6.25	0.351	13.15	38	1.10	US	7.9		Large heave. Pitching motion gradually built up to about 6° - divergent.
0.071	6.65	0.149	14.00	94	1.14	US	7.6	2.5	
0.108	6.00	0.228	12.62	55	1.08	S	7.3	0.8	Large oscillation in heave.
0.046	6.65	0.096	14.00	145	1.14	S	6.4		
0.017	4.00	0.035	8.41	240	0.88	S	6.2		
0.050	6.25	0.105	13.15	125	1.10	S	7.3		
0.067	6.00	0.140	12.61	90	1.08	B	7.5	0.4	Steady.
0.058	8.15	0.123	17.15	140	1.27	US	7.0		Oscillation building up. 3° amplitude at end of run.
0.117	6.50	0.246	13.68	56	1.13	US	7.5	4	Steady.
0.175	5.65	0.368	11.90	32	1.05	US	7.8	3.5	Steady.
0.142	5.65	0.298	11.90	40	1.05	S	5.8		

TABLE XV

WAVE TEST DATA FOR MODEL L

Point 5L. $C_{\Delta_o} = 2.75$, $C_V = 9.2$, $\eta = -2^o$.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Attitude degs.	Max. Amp. degs.	Remarks
0.033	8.00	0.070	16.83	240	1.25	S			
0.046	6.65	0.097	14.00	145	1.14	S	5.5		
0.050	12.00	0.105	25.26	240	1.56	US	6.5	3	Steady.
0.067	8.15	0.140	17.15	125	1.26	S	7.3		
0.083	10.40	0.176	21.90	125	1.44	B	6.5	1	Steady.
0.096	12.50	0.202	26.65	130	1.60	US	8.0		Erratic motion. Divergent oscillation with model leaving water with increasing jumps until max. of 5° oscillation reached, then damped out. Motion repeated.
0.100	9.00	0.211	18.94	90	1.34	US	7.4		Occasional kicks of 4° amplitude.
0.083	7.50	0.176	15.80	90	1.22	S	7.1		Occasional rapid flick of 2°
0.117	6.50	0.246	13.68	56	1.13	B	6.5	2	Intermittent, steady. Model periodically leaving water and steady at 6.5° whilst in air.
0.096	6.00	0.202	12.61	62	1.08	S	6.5		
0.125	7.50	0.263	15.80	60	1.22	US			Erratic oscillation. Model leaving water occasionally.
0.175	5.65	0.368	11.90	32	1.05	S	6.5		
0.142	5.65	0.298	11.90	40	1.05	S	6.9		
0.158	6.35	0.333	13.36	40	1.12	S	6.9		
0.167	7.00	0.351	14.72	42	1.17	US			Model thrown well clear of water.
0.208	6.25	0.439	13.15	30	1.10	US	6.5		Oscillation possibly building up. 6° amplitude at end of run.

/TABLE XVI

TABLE XVI

WAVE TEST DATA FOR MODEL L

Point 6L. $C_{\Delta_o} = 2.75$, $C_V = 6.9$, $\eta = -12^o$.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.033	5.00	0.070	10.50	150	0.99	S		
0.058	7.50	0.123	15.80	130	1.22	US	4	Not periodic.
0.050	7.50	0.105	15.80	150	1.22	B	2	Irregular.
0.042	6.25	0.087	13.15	150	1.10	US	5	Irregular.
0.071	5.00	0.149	10.51	70	0.99	US		Nearer a periodic oscillation of 3^o.
0.058	4.10	0.123	8.63	70	0.89	S		
0.113	5.85	0.237	12.30	52	1.07	US		Approaching periodic oscillation of 6^o.
0.087	4.80	0.184	10.10	55	0.97	US		Nearly steady oscillation of 5^o.
0.067	3.85	0.140	8.10	57	0.86	B		Nearly steady oscillation of 1.5^o.
0.050	5.00	0.105	10.51	100	0.99	B		Small irregular oscillations of about 0.8^o.
0.067	6.66	0.140	14.00	100	1.14	US	6.5	Two step porpoising.
0.117	4.65	0.246	9.79	40	0.95	US	5	Periodic.
0.092	4.00	0.193	8.41	43	0.88	US	5.5	Periodic.
0.083	3.35	0.175	7.05	40	0.80	US	3	Occasional kicks of 6^o.
0.067	2.65	0.140	5.58	40	0.70	S		
0.083	2.50	0.175	5.26	30	0.69	B	0.5	Steady.
0.100	3.00	0.211	6.31	30	0.75	US		Steady, diverging to 3^o amplitude at end of run.
0.033	6.65	0.070	14.00	200	1.14	S	0.2	Slight oscillation.
0.033	8.35	0.070	17.57	250	1.28	US		Periodic diverging oscillation of 4^o. Damping out.
0.042	8.30	0.087	17.47	200	1.28	B	2	Steady.
0.046	10.00	0.097	21.05	217	1.42	US		Periodic, 6^o and 3^o alternating.
0.025	6.25	0.053	13.15	250	1.10	S		
0.025	25.00	0.053	52.60	1000	2.58	B	1.5	Slow.
0.033	33.30	0.070	70.00	1000	3.27	B	0.7	Slow.
0.042	41.60	0.087	87.50	1000	3.95	S		
0.017	16.65	0.035	35.10	1000	1.92	B	1	
0.008	8.35	0.017	17.57	1000	1.28	S		
0.025	15.00	0.053	31.60	600	1.79	B	1.5	Periodic.
0.033	20.00	0.070	42.10	600	2.18	US	7	Steady.
0.025	20.00	0.053	42.10	800	2.18	US	2.75	Steady.
0.017	13.30	0.035	28.00	800	1.66	B	1	Steady.
0.050	40.00	0.105	84.20	800	3.82	B	1	Steady.
0.042	33.35	0.087	70.30	800	3.27	B	1	Steady.
0.042	26.65	0.087	56.10	640	2.71	B	1.5	Steady.
0.033	26.65	0.070	56.10	800	2.71	B	1	Occasional amplitude of 2^o.
0.058	35.00	0.123	73.70	600	3.41	B	1	Low frequency oscillation.
0.050	20.00	0.105	42.10	400	2.18	US	8	Two step porpoising.
0.121	33.35	0.254	70.30	280	3.27	US	2	Occasional 2.5^o.
0.092	33.35	0.193	70.30	360	3.27	B	<2	Very low frequency. One sudden kick of 4^o - damped out.
0.100	33.35	0.210	70.30	330	3.27	US	2	Occasional kick of 4^o.
0.062	33.35	0.132	70.30	530	3.27	B	1	
0.071	37.50	0.149	79.00	530	3.62	B	1	
0.058	28.00	0.123	59.00	480	2.83	B	2	Steady.
0.050	24.00	0.105	50.50	480	2.50	US	3	Steady.
0.067	32.00	0.140	67.30	480	3.16	B	1	Steady.
0.117	25.00	0.246	52.60	210	2.58	US	7	Irregular.
0.167	16.65	0.351	35.10	100	1.91	US	8	Irregular.
0.025	10.00	0.053	21.04	400	1.42	US	4	Irregular.
0.017	6.65	0.035	14.00	400	1.14	S		
0.067	16.65	0.140	35.00	250	1.92	US	6	Steady.

/TABLE XVII

TABLE XVII

WAVE TEST DATA FOR MODEL L

Point 7L. $C_{\Delta_o} = 2.75$, $C_V = 9.2$, $\eta = -12^o$.

h ft.	L ft.	h b	L b	L/h	Period of waves. secs.	Stability S/US/B	Attitude degs.	Max. Amp. degs.	Remarks
0.033	8.00	0.070	16.83	240	1.25	US		4	Irregular.
0.046	6.65	0.096	14.00	145	1.14	B	7.3		Alternate 1° and 2°.
0.017	4.00	0.035	8.41	240	0.88	B	8.7	1.9	
0.067	8.15	0.140	17.15	125	1.26	US	8.0	3	Steady.
0.050	6.25	0.105	13.15	125	1.10	B	7.8	1.5	Steady.
0.087	6.75	0.184	14.20	77	1.15	B	8.0	1	Steady.
0.100	9.00	0.211	18.94	90	1.34	US		6.5	Very erratic, with model leaving water occasionally.
0.083	7.50	0.176	15.80	90	1.22	B	8.0	1	Steady.
0.117	6.50	0.246	13.68	56	1.13	B	8.0	1	Steady.
0.142	8.00	0.298	16.82	56	1.26	US	7.5		Model thrown nose up clear of water.
0.125	7.50	0.263	15.80	60	1.22	US			Erratic. Model leaving water occasionally.
0.175	5.65	0.368	11.90	32	1.05	US	8.0	5	Irregular.
0.142	5.65	0.298	11.90	40	1.05	S	8.2		

TABLE XVIII

WAVE TEST DATA FOR MODEL L

Point 8L. $C_{\Delta_o} = 2.75$, $C_V = 8.2$, $\eta = -8^o$.

h ft.	L ft.	h b	L b	L/h	Period of waves. secs.	Stability S/US/B	Attitude degs.	Max. Amp. degs.	Remarks
0.033	8.00	0.070	16.83	240	1.25	US			Fairly steady with amplitude building up.
0.046	6.65	0.096	14.00	145	1.14	US	8.0	1	Occasional kicks down to 5.5°.
0.017	4.00	0.035	8.41	240	0.88	S	8.1		
0.050	6.25	0.105	13.15	125	1.10	US	7.4	2.2	Steady.
0.033	4.15	0.070	8.74	125	0.89	S	8.0		
0.087	6.75	0.184	14.20	77	1.15	B	7.5	2	Steady.
0.067	6.00	0.140	12.62	90	1.08	B	7.9	1.8	Steady.
0.100	9.00	0.211	18.94	90	1.34	US	9.0	7	Steady.
0.029	5.35	0.061	11.26	183	1.02	S	8.1		
0.117	6.50	0.246	13.68	56	1.13	US	8.0	3	Steady.
0.096	6.00	0.202	12.61	62	1.08	S	7.6		
0.175	5.65	0.368	11.90	32	1.05	S	8.0		
0.142	5.65	0.298	11.90	40	1.05	B	7.5	1	Steady. Occasional "kick" of 2°.
0.158	6.35	0.333	13.36	40	1.12	US	8.0	9	Steady.
0.208	6.25	0.439	13.15	30	1.10	S	8.2		
0.225	6.75	0.474	14.20	30	1.15	US			Very erratic motion.

/TABLE XIX

TABLE XIX

WAVE TEST DATA FOR MODEL L

Point 9L. $C_{\Delta_0} = 2.75$, $C_V = 9.2$, $\eta = -6^o$.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Attitude degs.	Max. Amp. degs.	Remarks
0.046	6.65	0.097	14.00	145	1.14	S	7.0		
0.033	8.00	0.070	16.82	240	1.25	S	7.3		Bouncing at constant attitude on every third or fourth wave crest.
0.050	12.00	0.105	25.26	240	1.56	US	7.0	3	Steady.
0.067	8.15	0.140	17.15	125	1.26	S	7.4		
0.083	10.40	0.176	21.90	125	1.44	US	7.5	7	Erratic. Nose of model thrown up by waves causing model to leave water frequently.
0.100	9.00	0.211	18.94	90	1.34	US	7.0	3	Steady.
0.083	7.50	0.176	15.80	90	1.22	US	8.8	4.5	Steady.
0.096	6.00	0.202	12.61	62	1.08	B	7.5	1	Steady.
0.117	6.50	0.246	13.68	56	1.13	B	7.3	1.5	Steady.
0.067	6.00	0.140	12.61	90	1.08	B	8.1	1.2	Steady.
0.125	7.50	0.263	15.80	60	1.22	US			Erratic. Model leaving water occasionally.
0.175	5.65	0.368	11.90	32	1.05	US	7.0	3	Steady.
0.142	5.65	0.298	11.90	40	1.05	S	7.7		

TABLE XX

WAVE TEST DATA FOR MODEL L

Point 10L. $C_{\Delta_0} = 2.75$, $C_V = 6.9$, $\eta = -4^o$.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Attitude degs.	Max. Amp. degs.	Remarks
0.033	8.00	0.070	16.83	240	1.25	B			Fairly steady. Occasional "flick" of 2^o.
0.046	6.65	0.096	14.00	145	1.14	B	8.0	1	
0.046	6.65	0.096	14.00	145	1.14	B	7.5	1	Steady.
0.033	8.00	0.070	16.83	240	1.25	S	8.0		
0.050	12.00	0.105	25.26	240	1.56	US	6.0	4	Spasmodic.
0.067	8.15	0.140	17.15	125	1.26	US	7.6	2.7	Erratic.
0.050	6.25	0.105	13.15	125	1.10	S	8.2		
0.087	6.75	0.184	14.20	77	1.15	US	7.8	4.5	Steady.
0.067	6.00	0.140	12.62	90	1.08	S	8.3		
0.117	6.50	0.246	13.68	56	1.13	US	8.3	6.5	Steady.
0.096	6.00	0.202	12.61	62	1.08	US	8.0	7	Steady.
0.083	5.00	0.176	10.52	60	0.99	B	7.0	1.5	Steady.
0.175	5.65	0.368	11.90	32	1.05	US	8.0	7	Steady.
0.142	5.65	0.298	11.90	40	1.05	US	9.0	10	Steady.
0.125	5.00	0.263	10.52	40	0.99	US	7.8	5.5	Steady.
0.108	4.35	0.228	9.16	40	0.92	US	8.5	8	Steady.
0.092	3.65	0.193	7.69	40	0.84	US	7.5	4	Steady.
0.079	3.35	0.167	7.05	42	0.80	S	8.0		
0.083	2.50	0.176	5.26	30	0.68	B	8.0	1	Steady.
0.100	3.00	0.210	6.31	30	0.75	S	8.3		
0.117	3.50	0.246	7.36	30	0.82	US	7.5		Oscillation building up; 6^o at end of run.

/TABLE XXI

TABLE XXI

WAVE TEST DATA FOR MODEL L

Point 11L. $C_{\Delta_0} = 2.75$, $C_V = 9.2$, $\eta = -1^{\circ}$.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.033	5.00	0.070	10.50	150	0.99	S		
0.058	7.50	0.123	15.80	129	1.22	S		
0.071	11.25	0.149	23.70	159	1.51	S		
0.087	11.65	0.184	24.55	133	1.54	S		
0.096	13.00	0.202	27.40	125	1.64			Small erratic oscillations with occasional skips of 6°.
0.108	10.00	0.228	21.05	92	1.42	US		Occasional skips of 9° amplitude.
0.087	9.20	0.184	19.37	105	1.35	S		
0.150	9.95	0.316	20.90	66	1.41	US		Thrown well clear of water.
0.142	9.35	0.298	19.70	66	1.37	US		An occasional nose up "flick" of 4°.
0.129	7.50	0.272	15.80	58	1.22	S		
0.192	6.65	0.403	14.00	35	1.14	B	1.5	Steady.
0.208	7.30	0.439	15.37	35	1.20	US		Bouncing clear of water.
0.092	16.50	0.193	34.70	180	1.90	US	5	Bouncing from wave crest to wave crest with erratic pitching movement.
0.063	13.50	0.132	28.40	216	1.68	B	2	Bouncing from wave crest to wave crest.
0.075	13.50	0.158	28.40	180	1.68	S		
0.067	16.50	0.140	34.70	248	1.90	US	5	Steady. Bouncing from wave crest to wave crest.
0.071	16.50	0.149	34.70	233	1.90	US	4	Bouncing. Irregular oscillations
0.050	11.00	0.105	23.18	220	1.49	B	0.8	Very low frequency oscillations.
0.050	12.50	0.105	26.30	250	1.60	S		

/TABLE XXII

TABLE XXII

WAVE TEST DATA FOR MODEL L

Point 12L. $C_{\Delta_o} = 2.75$, $C_V = 8.4$, $\eta = 0^o$.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.033	5.00	0.070	10.50	150	0.99	S		
0.058	7.50	0.123	15.80	129	1.22	B	1.5	Irregular.
0.071	11.25	0.149	23.70	159	1.51	US	8	Irregular. Tendency to leave water.
0.067	10.00	0.140	21.02	150	1.42	S		
0.108	10.00	0.228	21.05	92	1.42	US		Small skips of 4^o interspersed with skips of 8^o.
0.087	9.20	0.184	19.37	105	1.35	S		
0.150	9.95	0.316	20.90	66	1.41	US		Occasional bounces clear of water.
0.142	9.35	0.298	19.70	66	1.37	US	6	Erratic.
0.129	7.50	0.272	15.80	58	1.22	US		Model bouncing well clear of water.
0.117	7.00	0.246	14.72	60	1.17	US		Divergent, 5^o at end of run.
0.104	6.00	0.219	12.63	58	1.07	S		
0.133	6.00	0.281	12.63	45	1.07	S		
0.150	6.00	0.316	12.63	40	1.07	B	2	Periodic.
0.192	6.65	0.403	14.00	35	1.14	US		Erratic motion. Model leaving water.
0.175	6.15	0.368	12.95	35	1.09	B	1.5	Oscillating.
0.242	6.25	0.509	13.15	26	1.10	US		Erratic bouncing. Wave system poor.
0.062	13.50	0.132	28.40	216	1.68	US		Erratic pitching movement.
0.050	11.00	0.105	23.18	220	1.49	S		
0.050	12.50	0.105	26.30	250	1.60	US	6.5	Irregular.
0.042	10.40	0.087	21.90	250	1.44	S		

TABLE XXIII

WAVE TEST DATA FOR MODEL L

Point 13L. $C_{\Delta_o} = 2.75$, $C_V = 9.5$, $\eta = 0^o$.

h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Max. Amp. degs.	Remarks
0.033	5.00	0.070	10.50	150	0.99	S		
0.058	7.50	0.123	15.80	129	1.22	S		
0.071	11.25	0.149	23.70	159	1.51	S		
0.087	11.65	0.184	24.55	133	1.54	US	2-3	Occasional bounces. One of 7^o leaving water.
0.108	10.00	0.228	21.05	92	1.42	US		Model bouncing well clear of water.
0.087	9.20	0.184	19.37	105	1.35	S		
0.150	9.95	0.316	20.90	66	1.41	US		Bouncing well clear of water.
0.142	9.35	0.298	19.70	66	1.37	US		Steady except for one "hop" of 7^o amplitude.
0.129	7.50	0.272	15.80	58	1.22	S		
0.192	6.65	0.403	14.00	35	1.14	S		
0.208	7.30	0.439	15.37	35	1.2	US		Steady except for one skip of 6o amplitude.
0.062	13.50	0.132	28.40	216	1.68	S		
0.075	13.50	0.158	28.40	180	1.68	B	1	Steady.
0.092	16.50	0.193	34.70	180	1,90	US	6	Erratic. Bouncing from wave crest to wave crest.

/TABLE XXIV

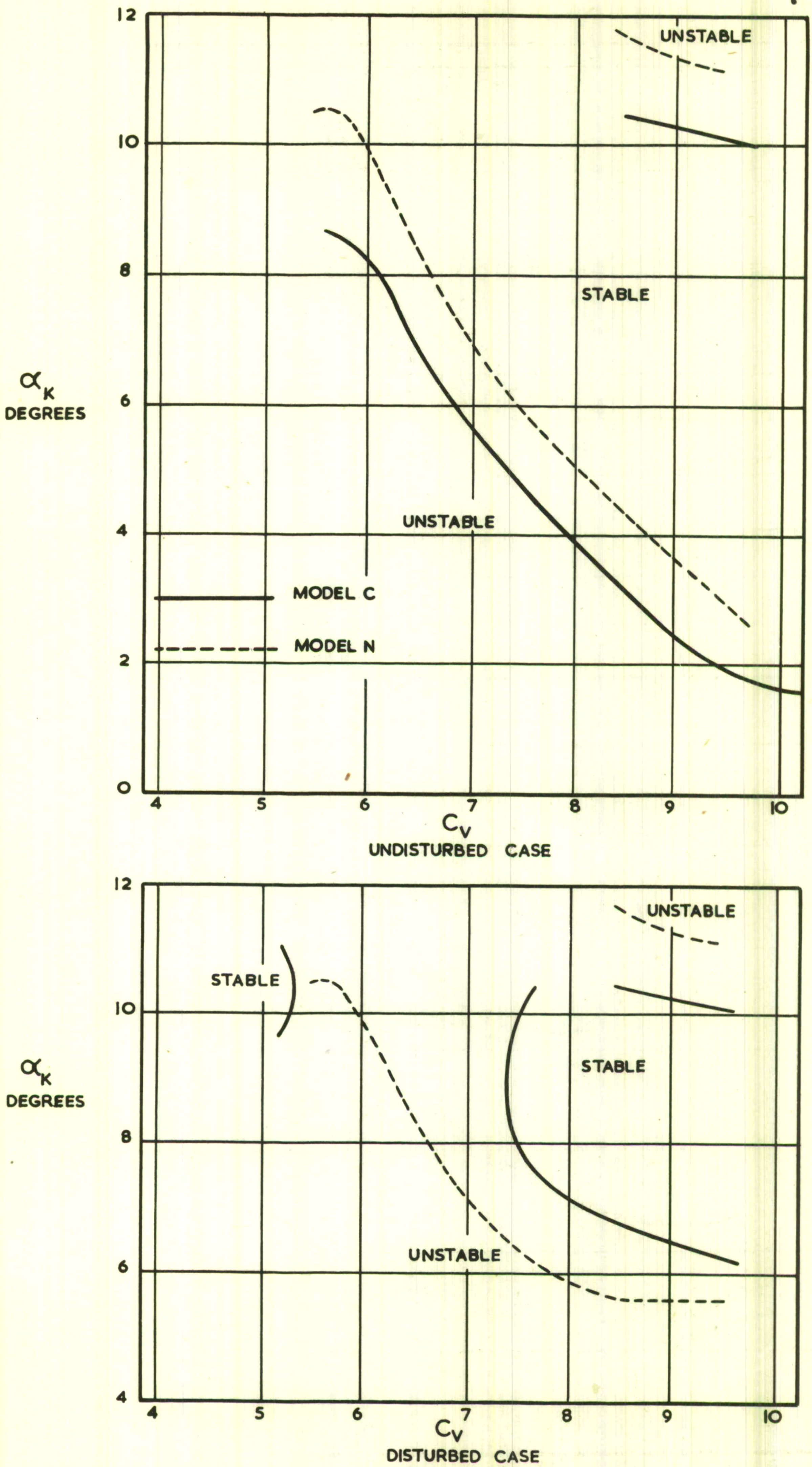
TABLE XXIV

WAVE TEST DATA FOR MODEL L

Point 14L. $C_{\Delta_0} = 2.75$, $C_V = 6.9$, $\eta = +4^{\circ}$.

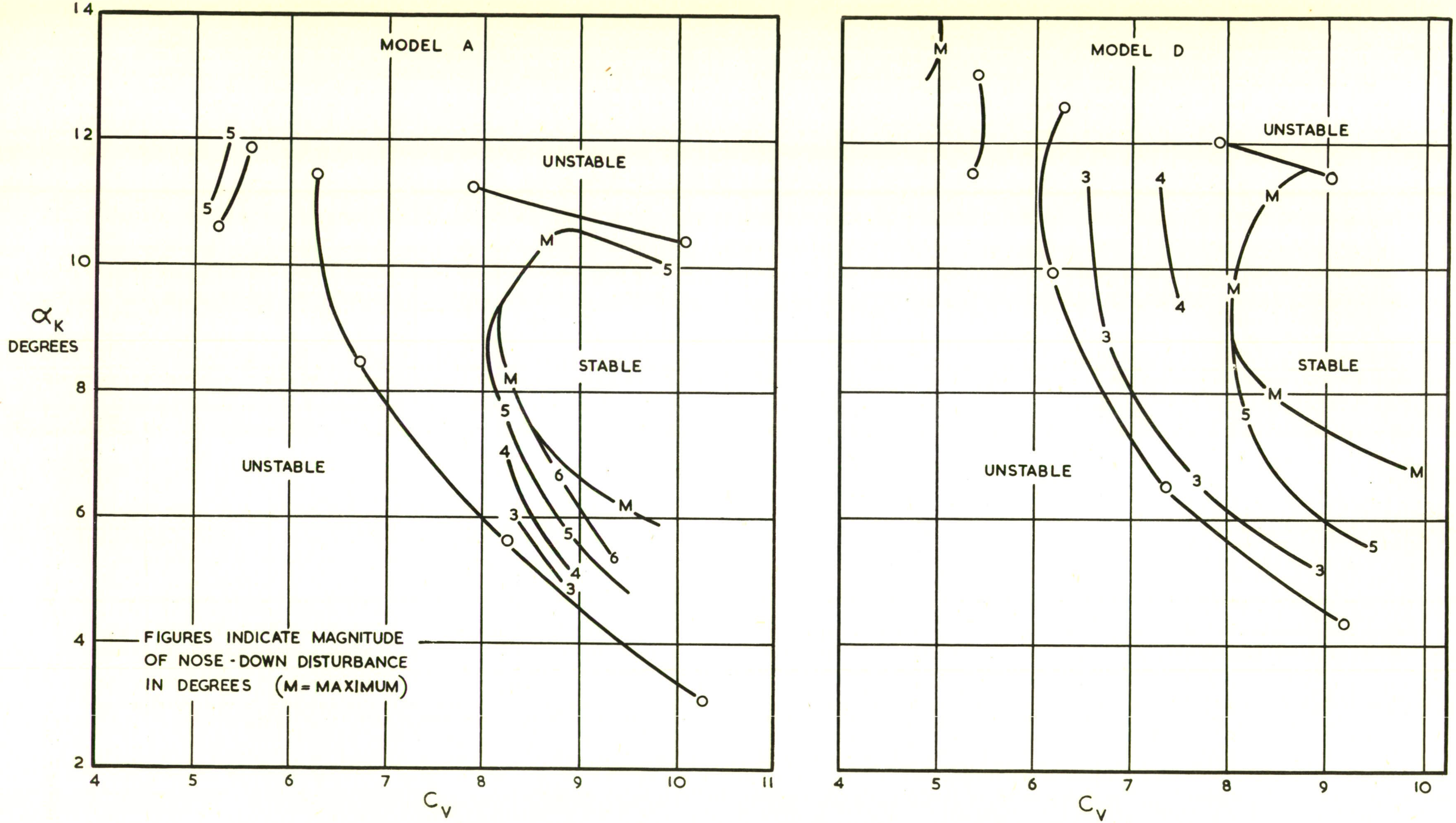
h ft.	L ft.	h/b	L/b	L/h	Period of waves. secs.	Stability S/US/B	Attitude degs.	Max. Amp. degs.	Remarks
0.033	8.00	0.070	16.82	240	1.25	B	6.5	1.	
0.050	12.00	0.105	25.26	240	1.56	US	7.5	7.5	Alternating.
0.067	8.15	0.140	17.15	125	1.26	B	7.0	1.4	
0.083	10.40	0.176	21.90	125	1.44	US	7.0	8	Steady.
0.100	9.00	0.211	18.94	90	1.34	US	7.0	9	Steady.
0.083	7.50	0.176	15.80	90	1.22	US	7.0	3.5	Steady.
0.096	6.00	0.202	12.61	62	1.08	US	7.5	8	Steady.
0.067	6.00	0.140	12.61	90	1.08	B	6.8	1.4	Steady.
0.083	5.00	0.176	10.52	60	0.99	B	7.1	0.5	Steady.
0.175	5.65	0.368	11.90	32	1.05	US	7.5	8	Steady.
0.142	5.65	0.298	11.90	40	1.05	US	7.5	8	Steady.
0.125	5.00	0.263	10.52	40	0.99	US	8.5		Divergent. Reached 6° amplitude at end of run.
0.108	4.35	0.228	9.16	40	0.92	US	7.5		Oscillating, possibly building up to 4° amplitude at end of run.
0.092	3.65	0.193	7.69	40	0.84	S	6.8		
0.100	3.00	0.210	6.31	30	0.75	S	7.3		
0.083	2.50	0.176	5.26	30	0.68	S	6.3		
0.117	3.50	0.246	7.36	30	0.82	S	6.8		
0.133	4.00	0.281	8.41	30	0.88	US	7.0		Oscillation building up. 5° amplitude at end of run.

FIG.1.



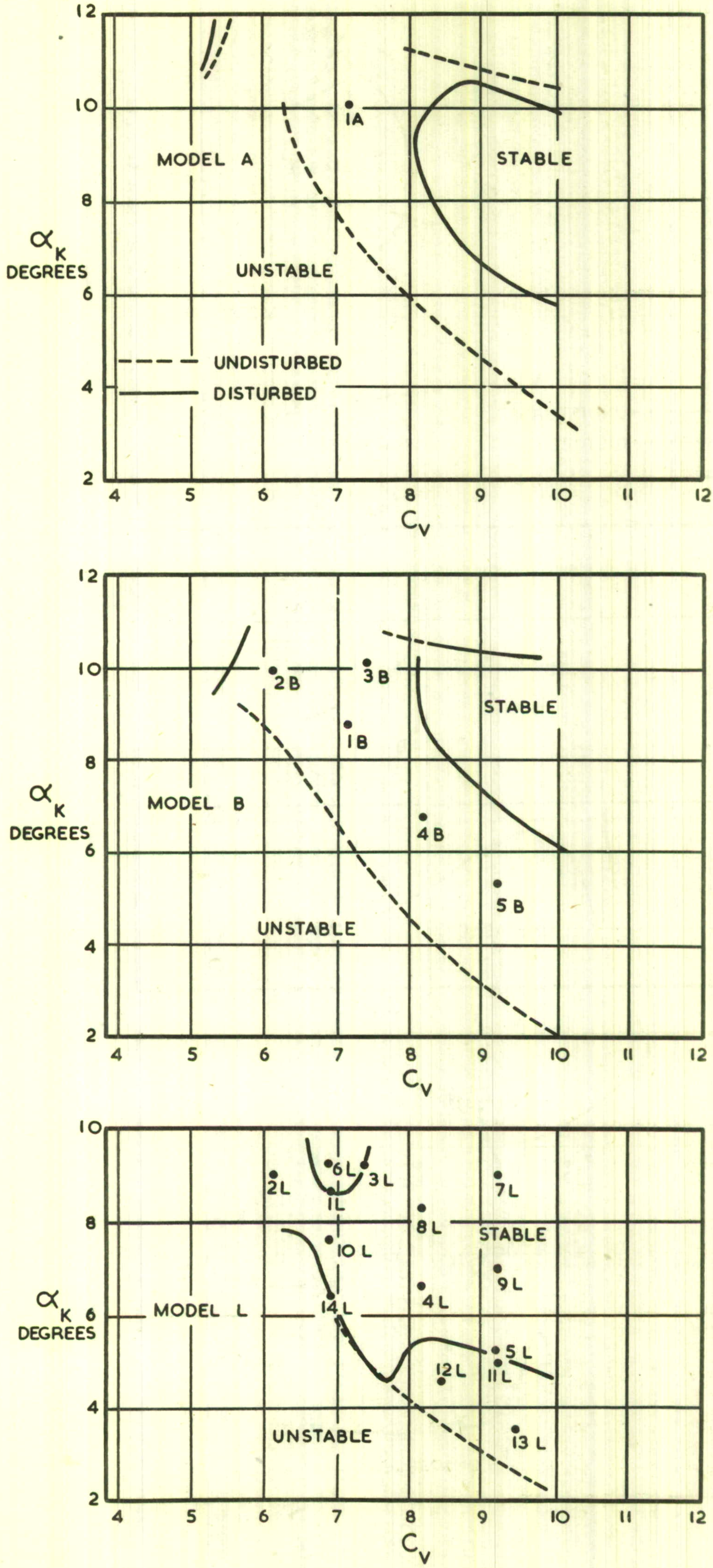
COMPARISON OF LONGITUDINAL STABILITY LIMITS FOR MODELS C AND N

FIG. 2.



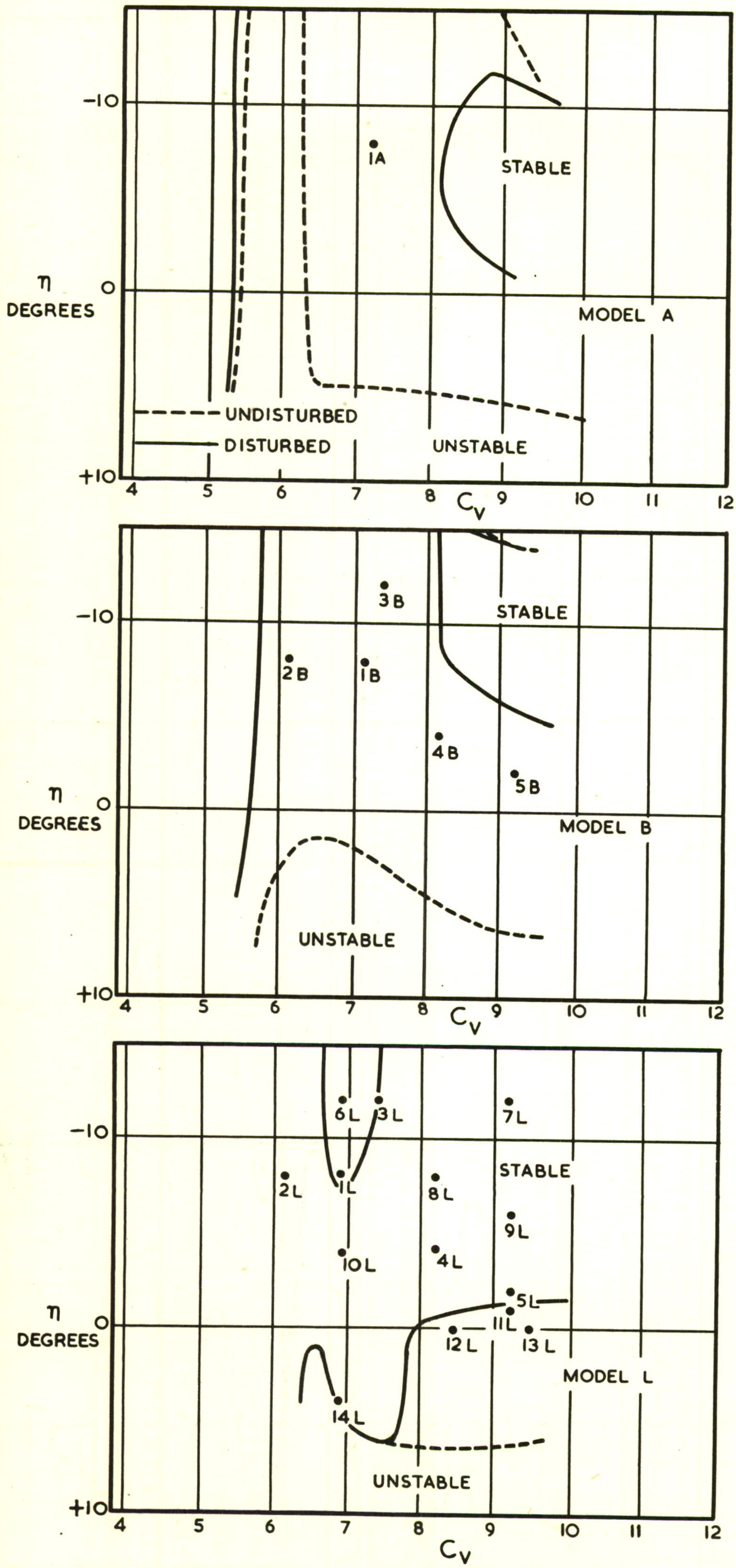
LONGITUDINAL STABILITY LIMITS FOR VARIOUS DEGREES OF DISTURBANCE

FIG. 3.



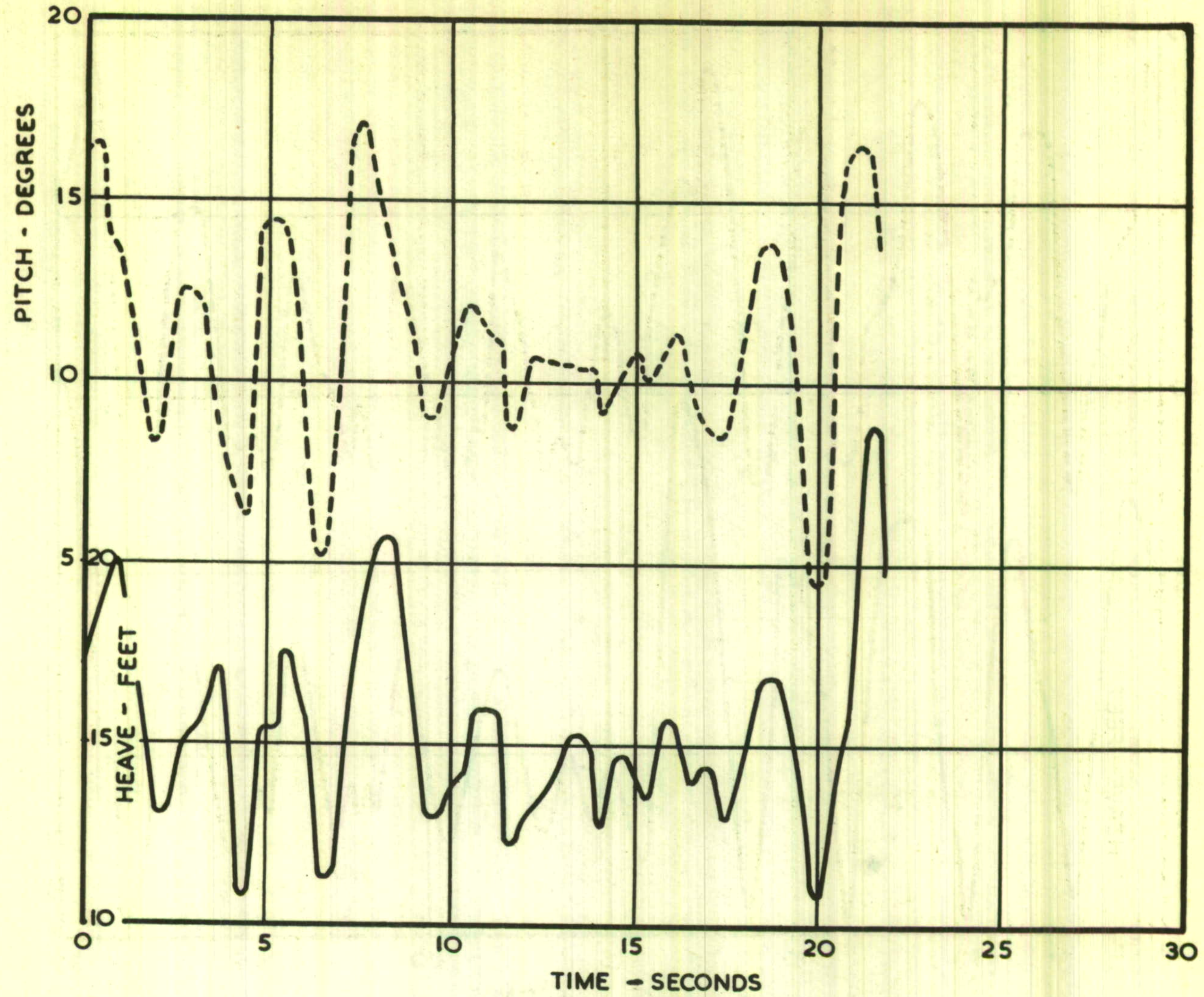
RELATION BETWEEN POINTS INVESTIGATED AND STABILITY LIMITS

FIG. 4.

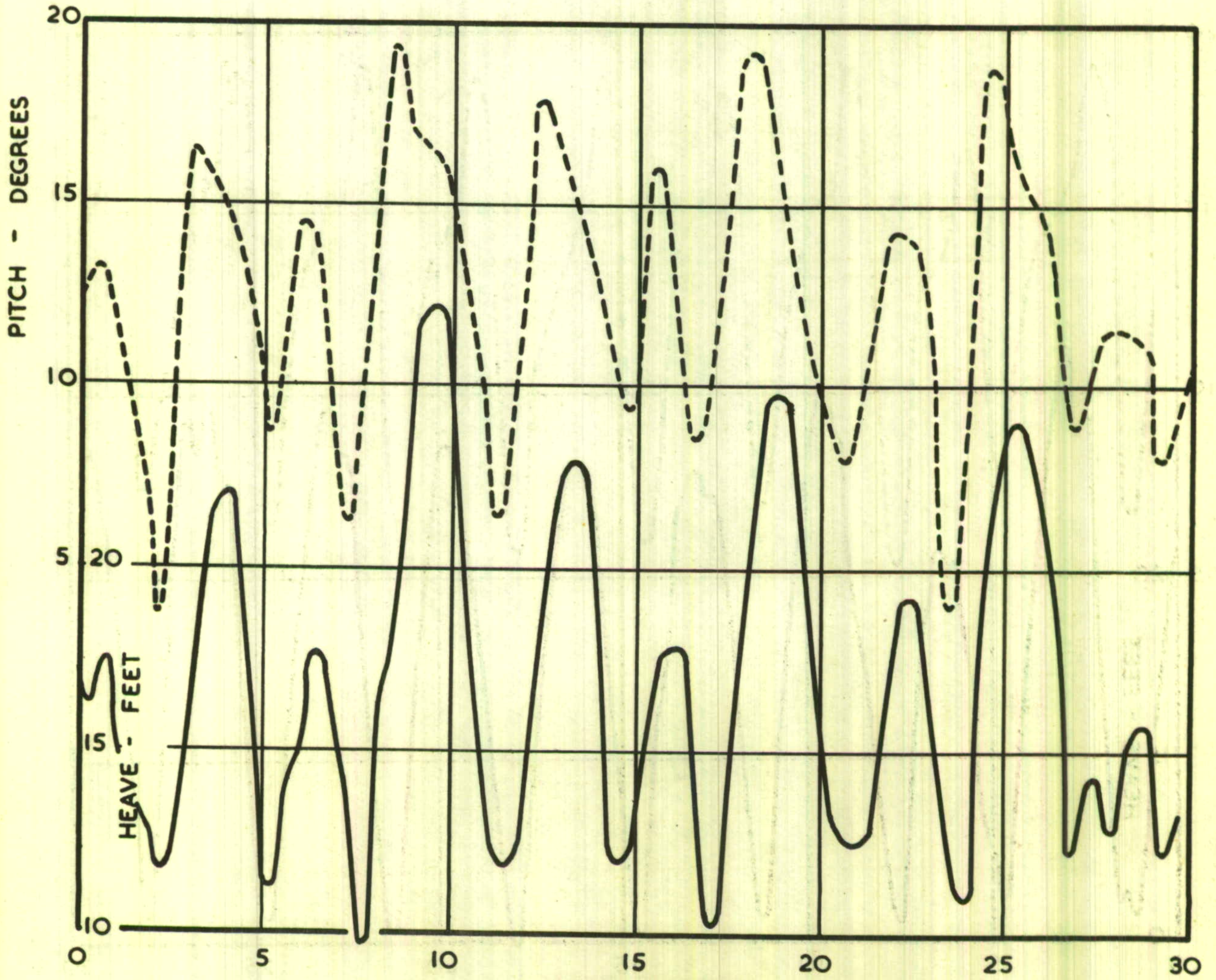


RELATION BETWEEN POINTS INVESTIGATED AND STABILITY LIMITS

FIG. 5.

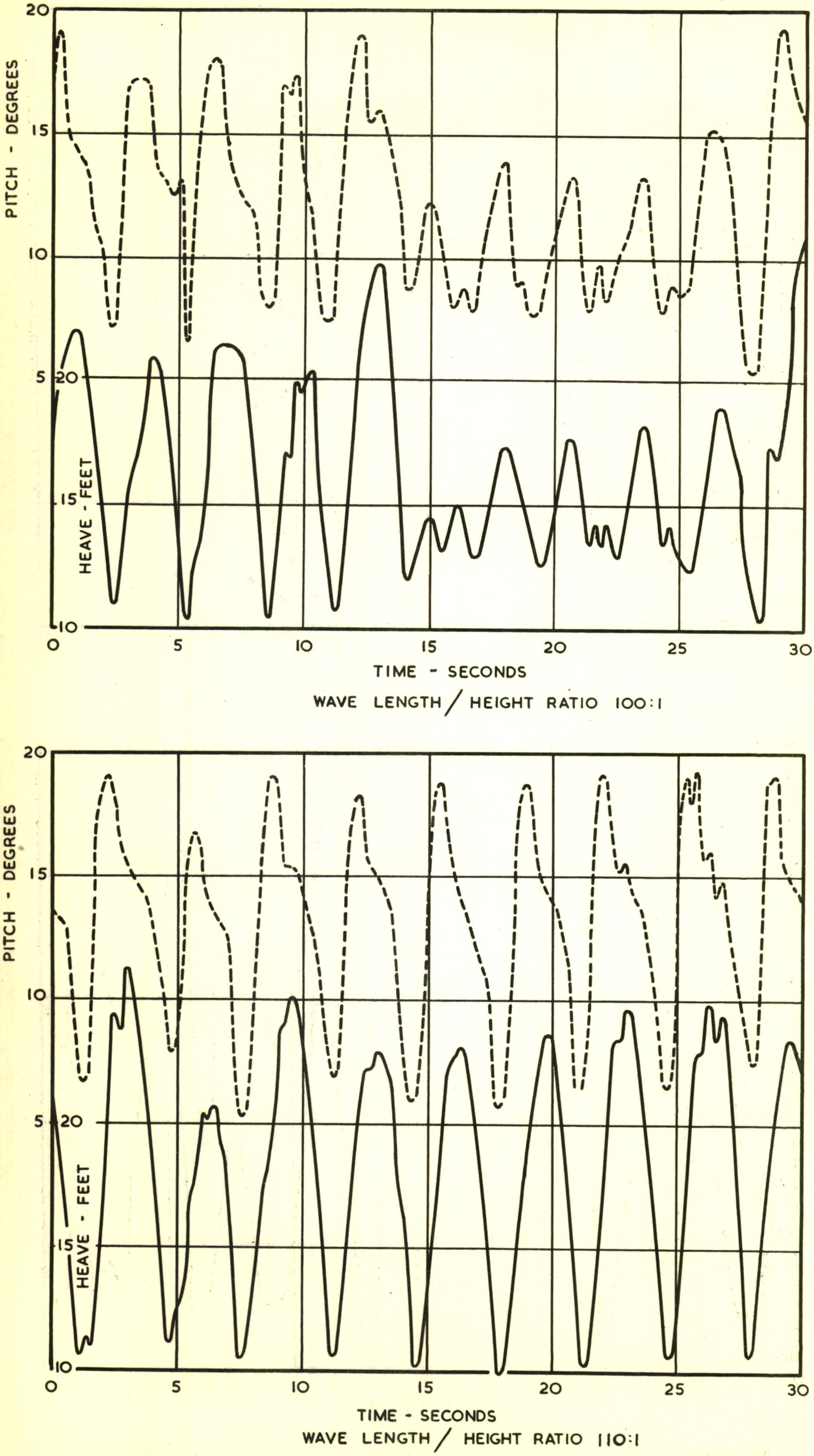


WAVE LENGTH / HEIGHT RATIO 80:1



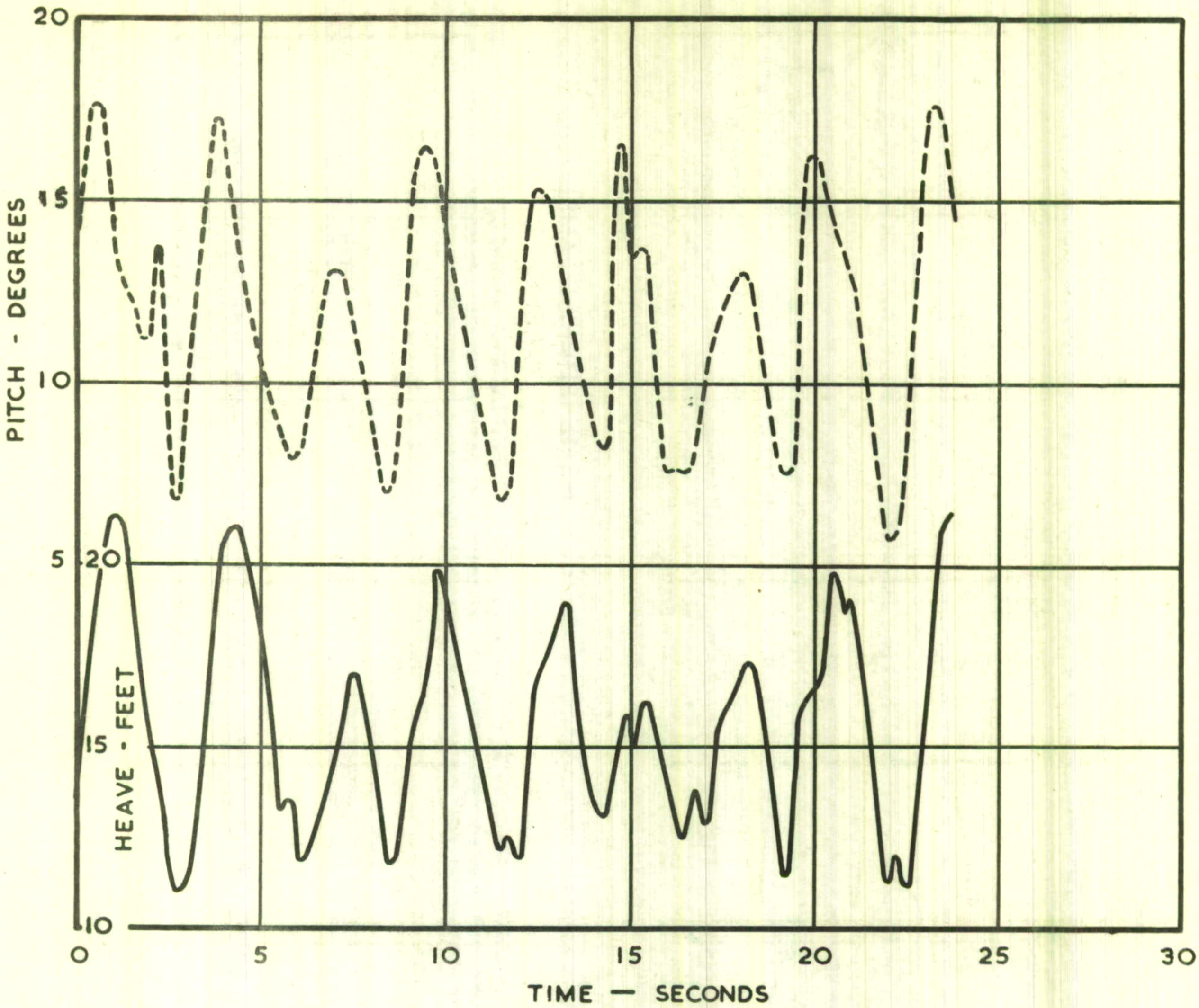
WAVE LENGTH / HEIGHT RATIO 90:1

MOTION OF MODEL A IN WAVES OF HEIGHT 2·35 FT

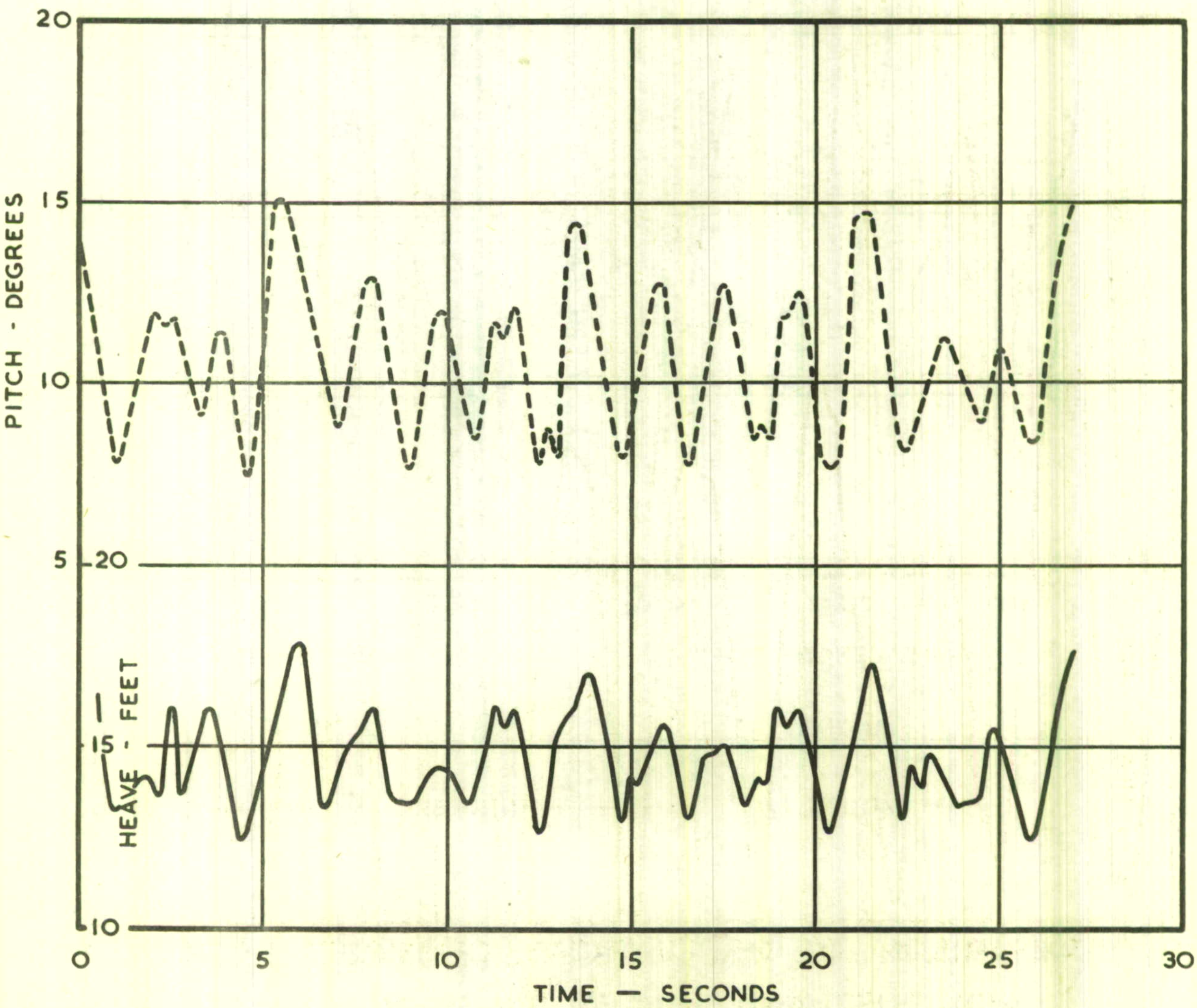


MOTION OF MODEL A IN WAVES OF HEIGHT 2·35 FT.

FIG. 7.



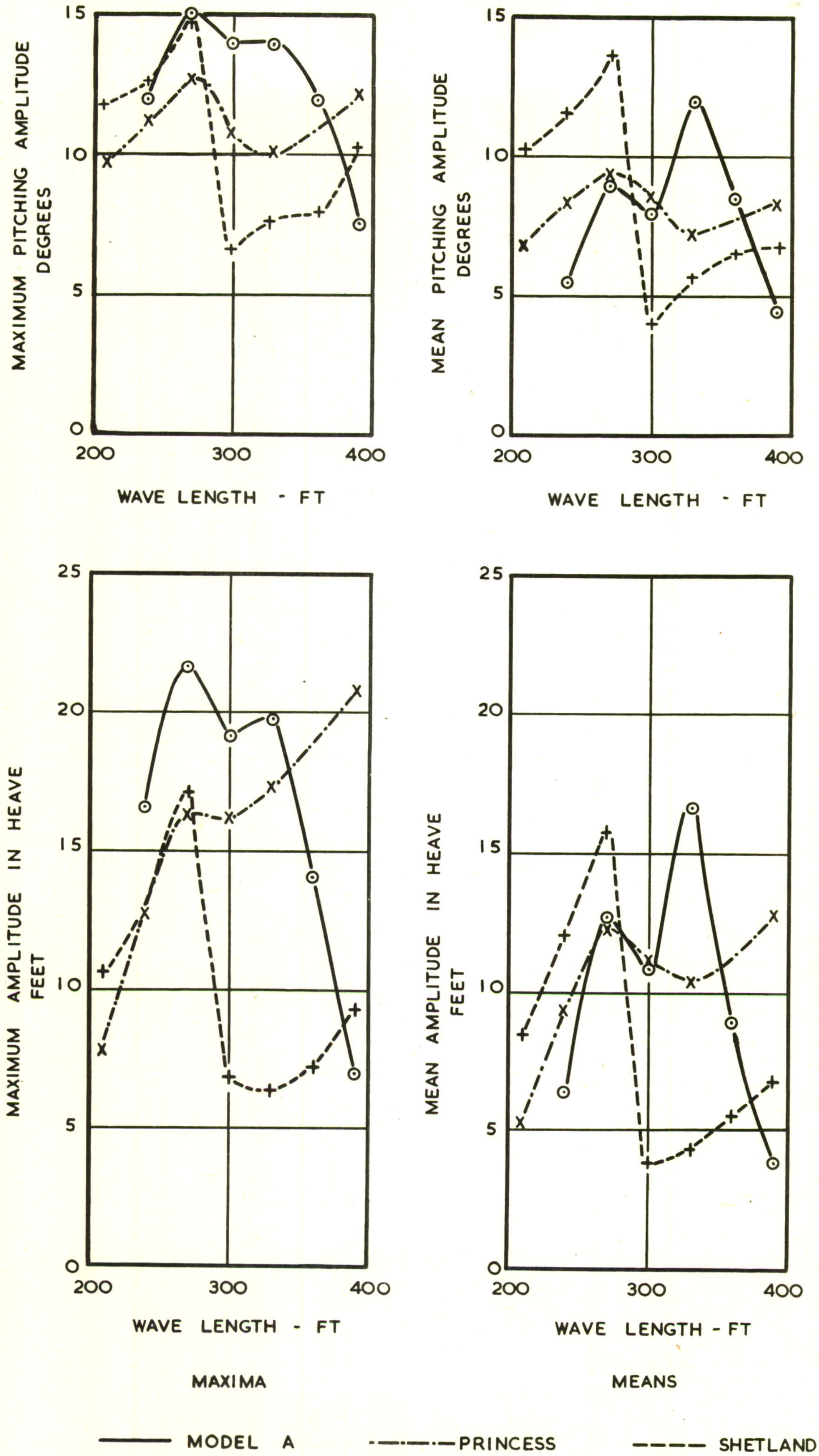
WAVE LENGTH / HEIGHT RATIO 120 : 1



WAVE LENGTH / HEIGHT RATIO 130 : 1

MOTION OF MODEL A IN WAVES OF HEIGHT 2·35 FT

FIG. 8.



COMPARISON OF OSCILLATIONS OF MODEL A PRINCESS AND SHETLAND SCALED TO PRINCESS SIZE

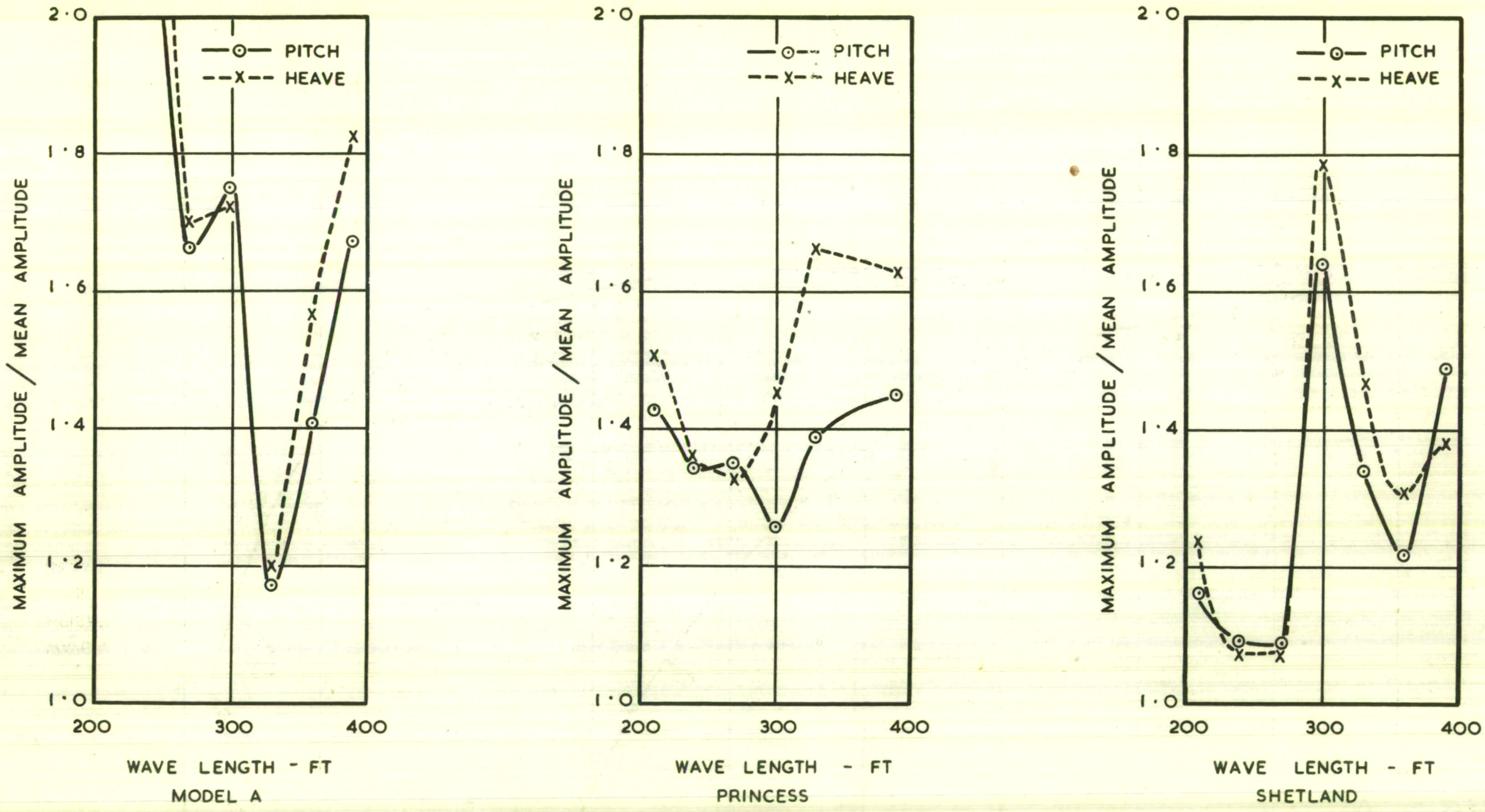
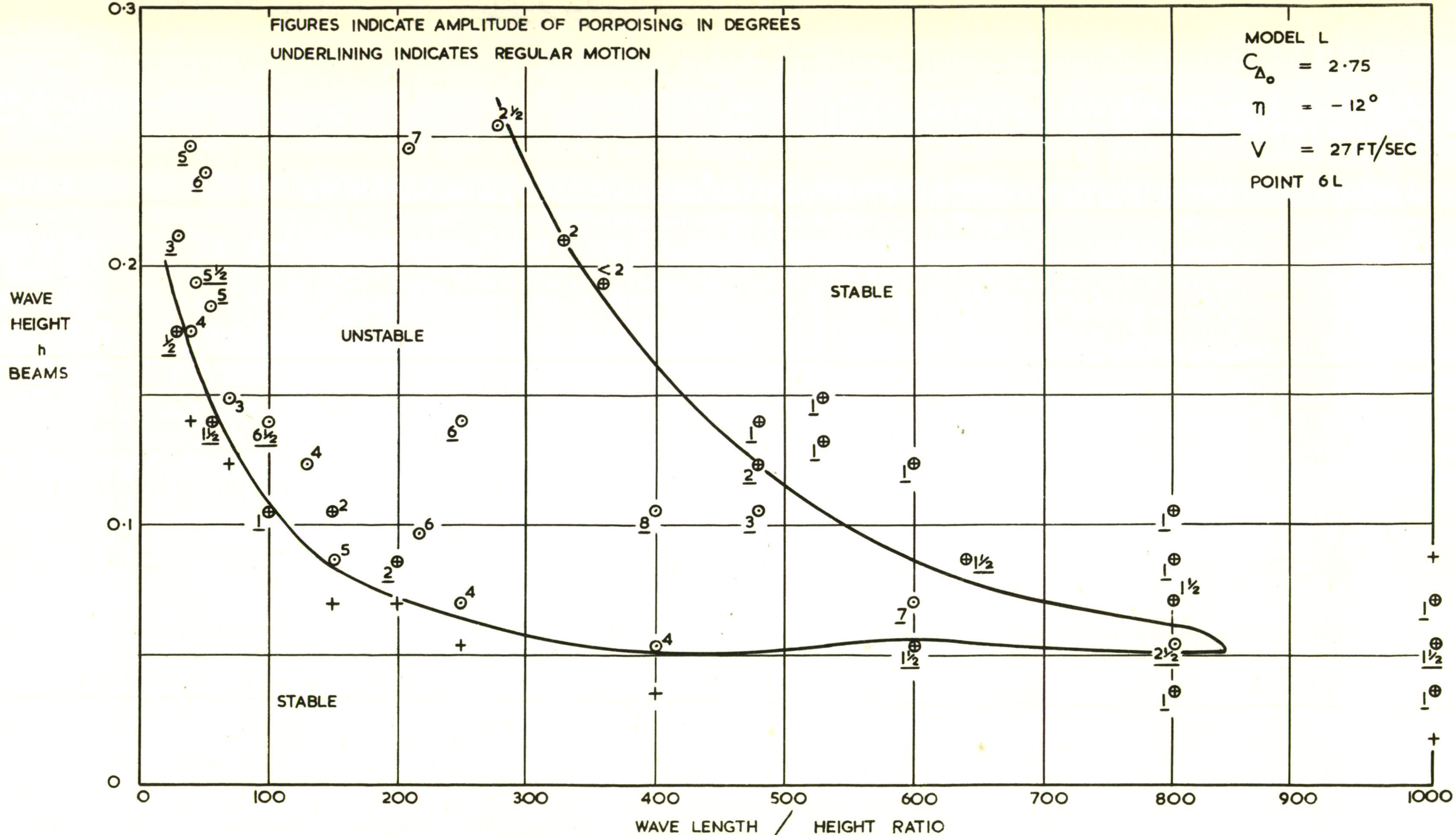


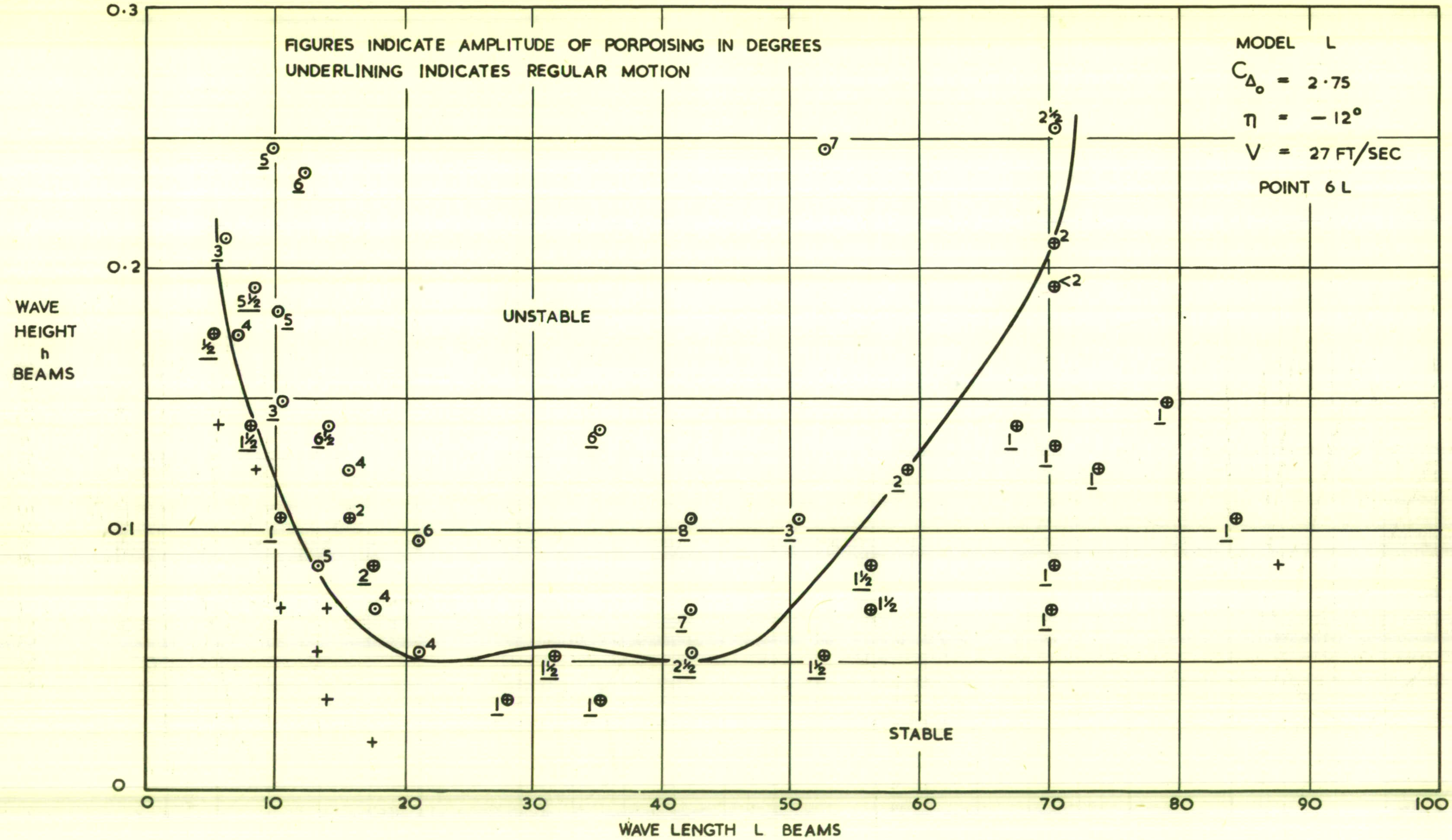
FIG. 9.

COMPARISON OF MAXIMUM / MEAN AMPLITUDES OF OSCILLATION FOR MODEL A PRINCESS AND SHETLAND



TYPICAL WAVE DIAGRAM ON A WAVE LENGTH / HEIGHT RATIO BASE

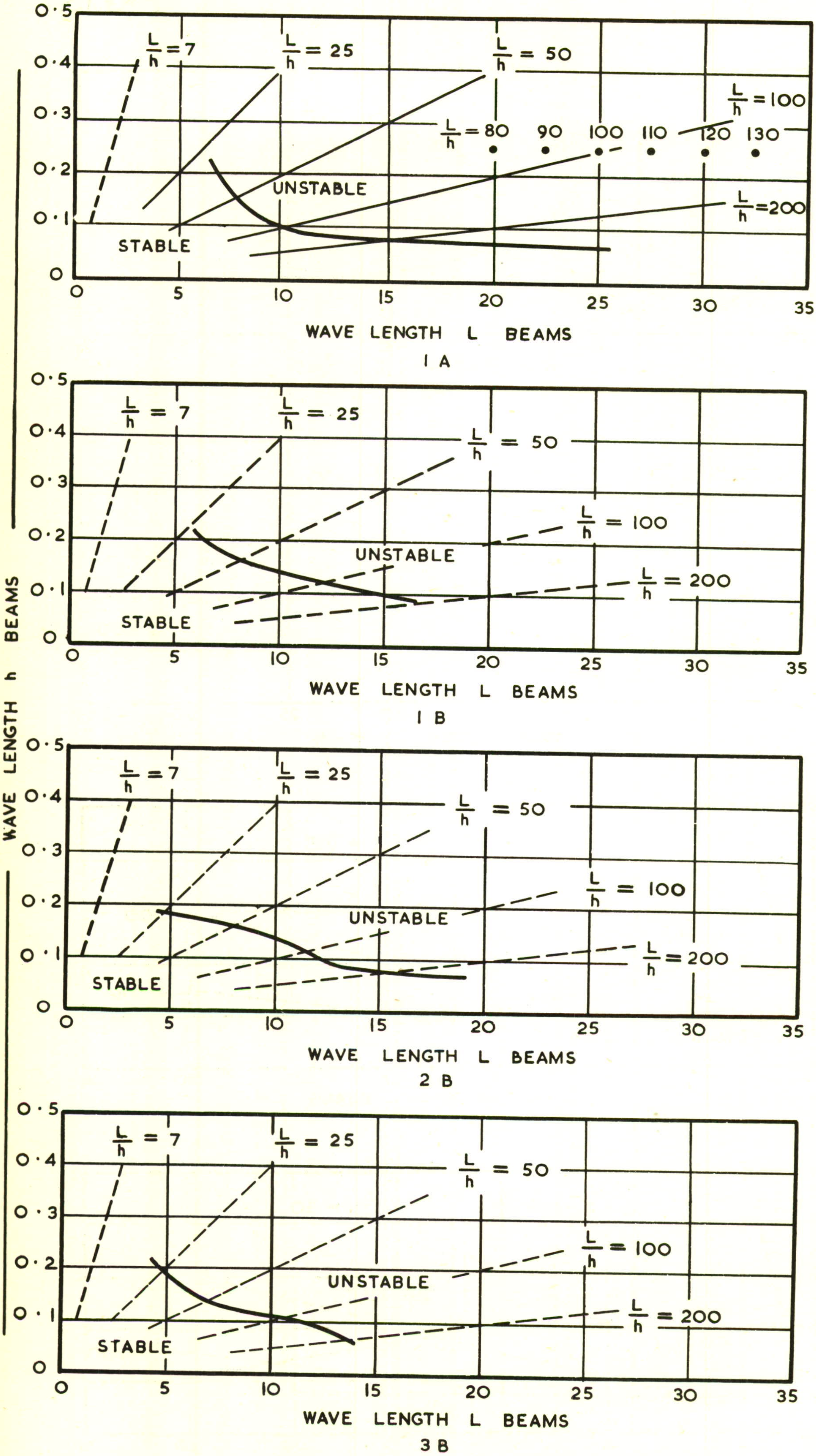
FIG.10.



TYPICAL WAVE DIAGRAM ON A WAVE LENGTH BASE

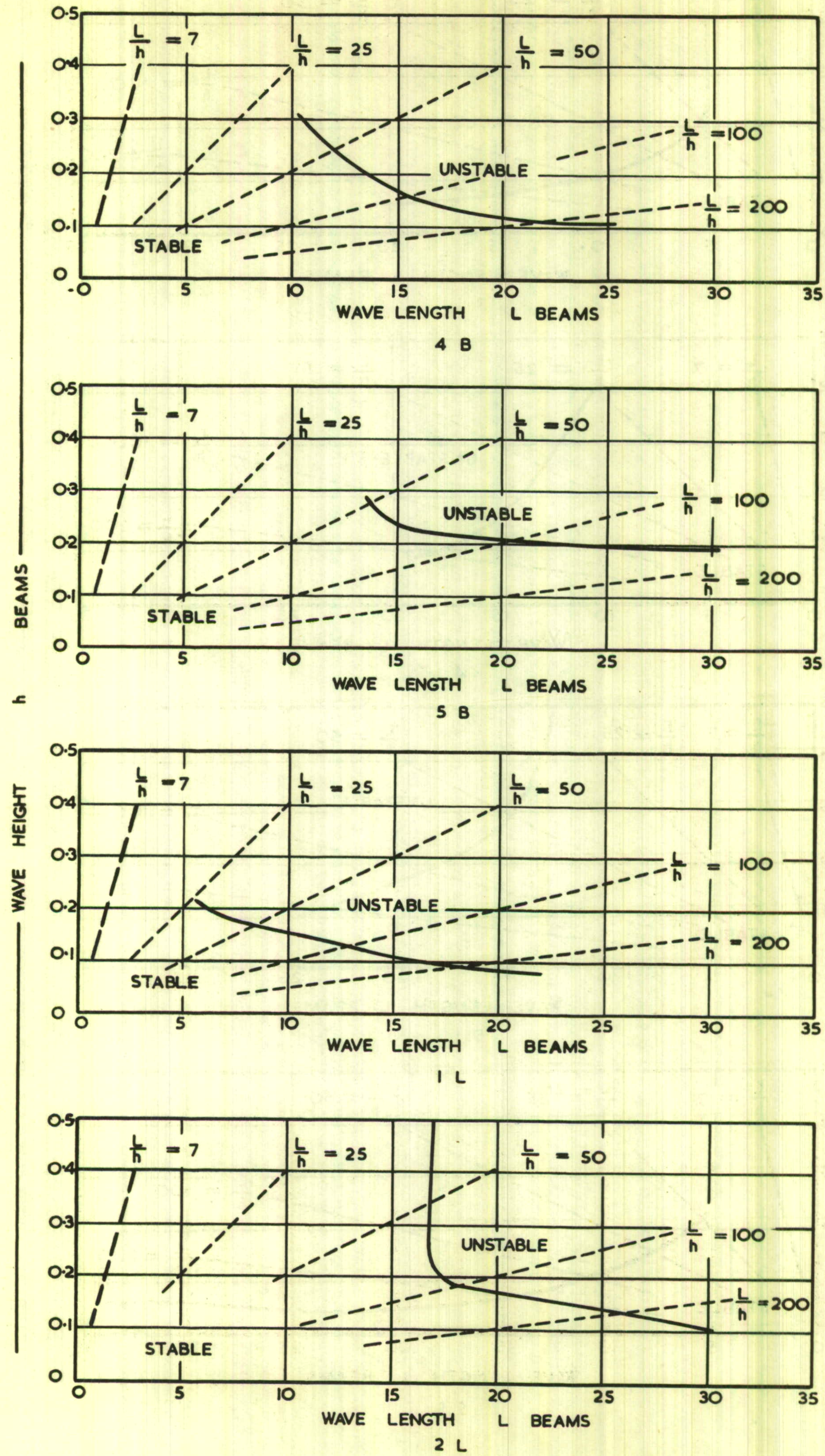
FIG. 11.

FIG. 12.



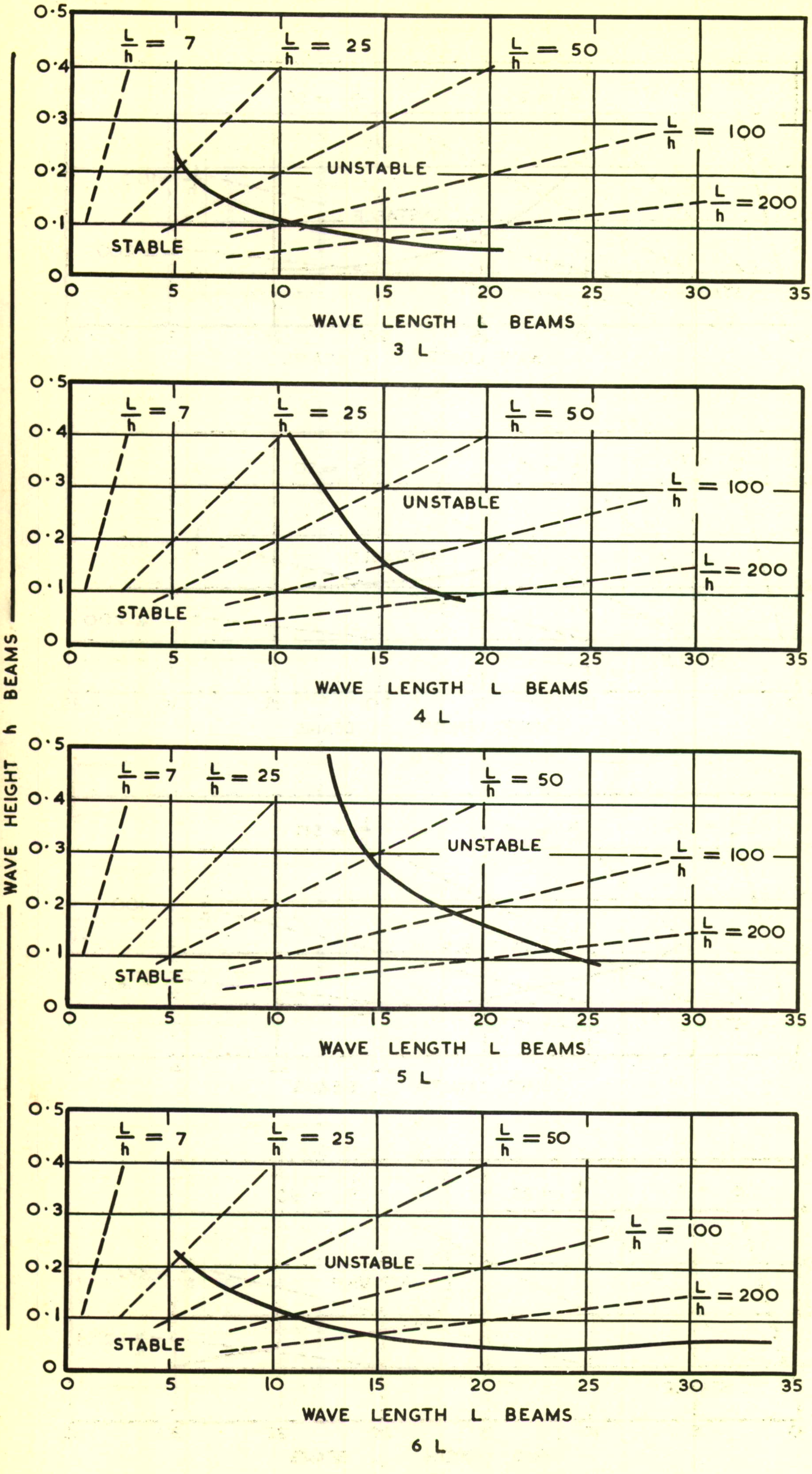
MODEL WAVE DIAGRAMS

FIG. 13.



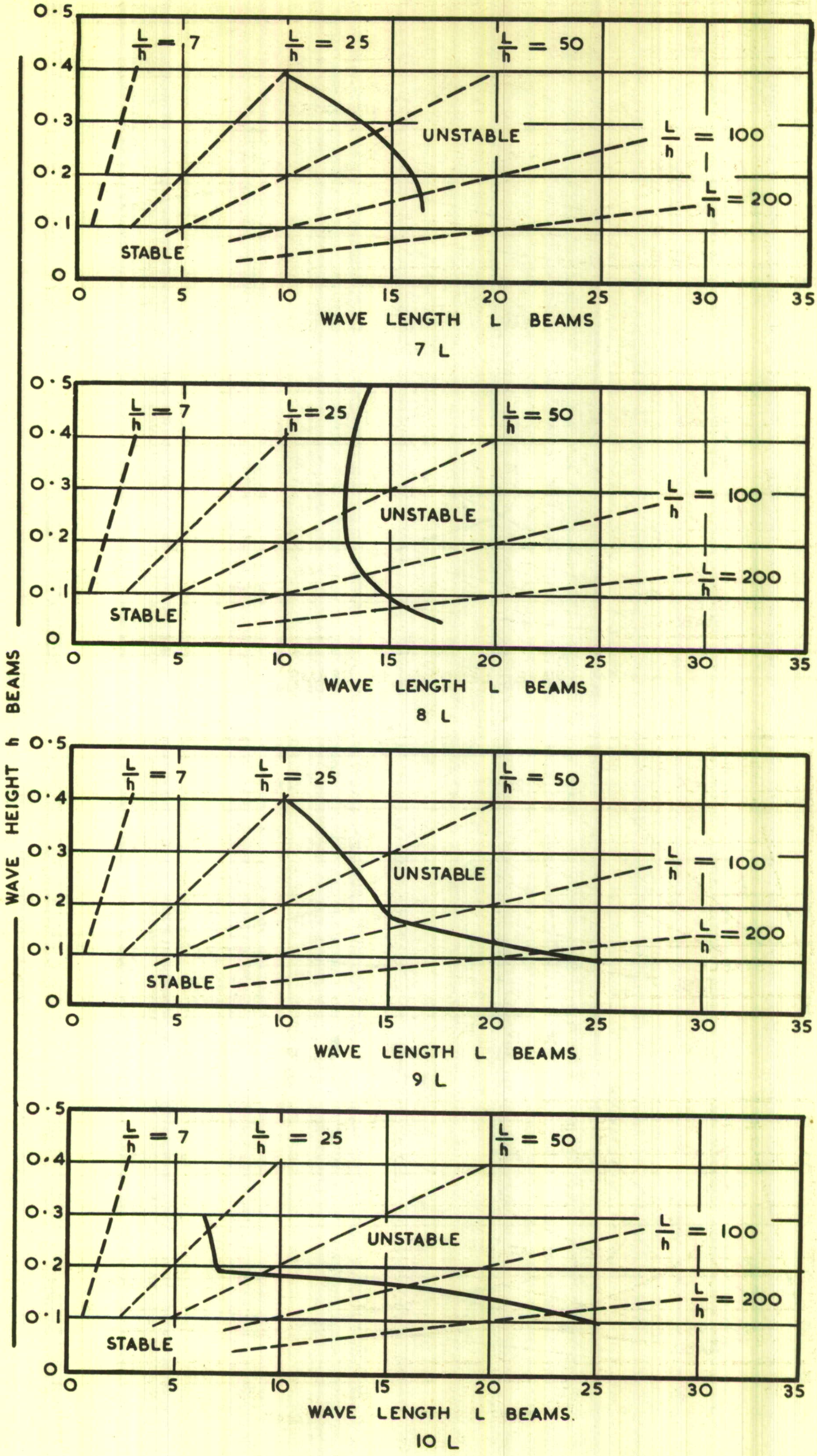
MODEL WAVE DIAGRAMS

FIG. 14.



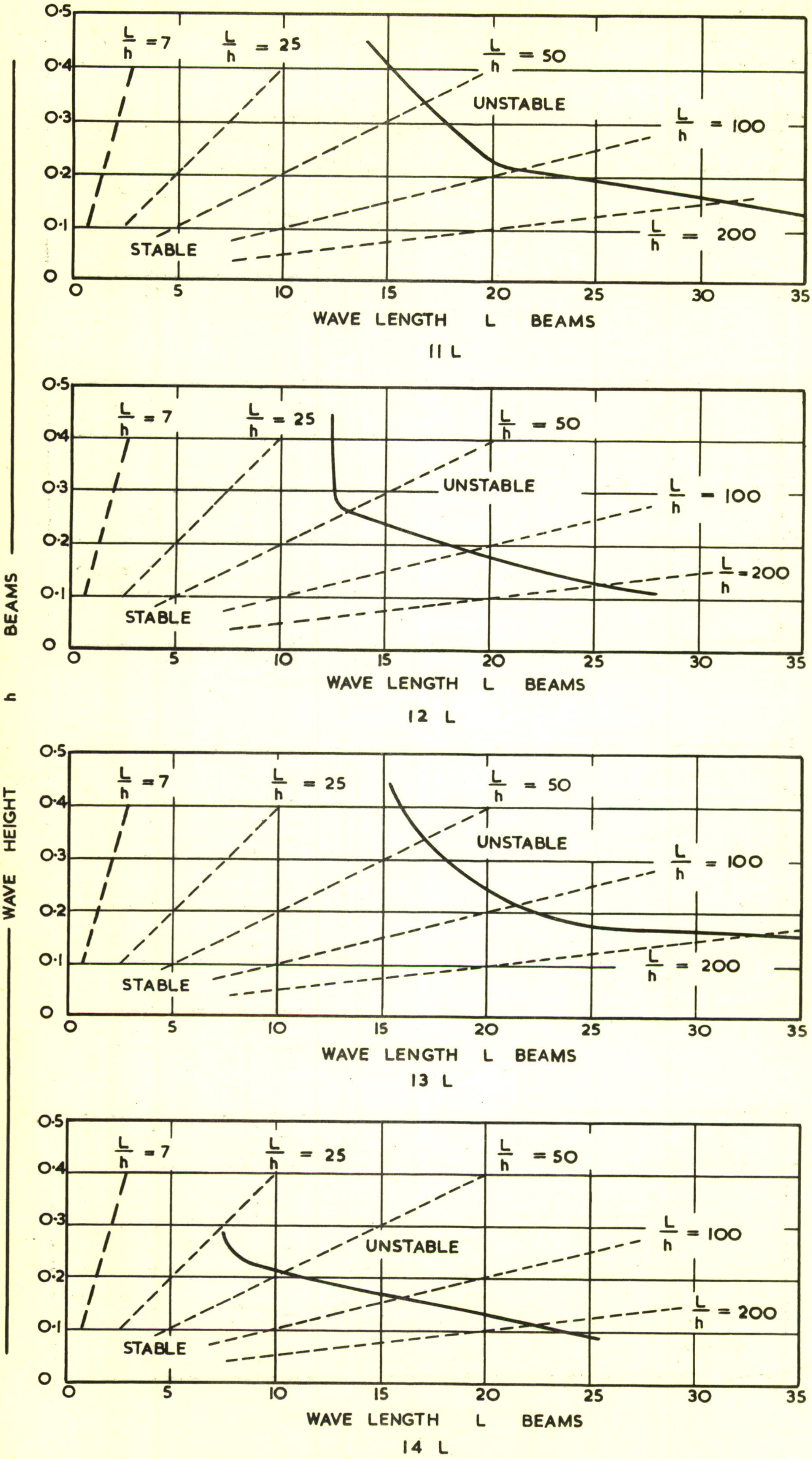
MODEL WAVE DIAGRAMS

FIG. 15.



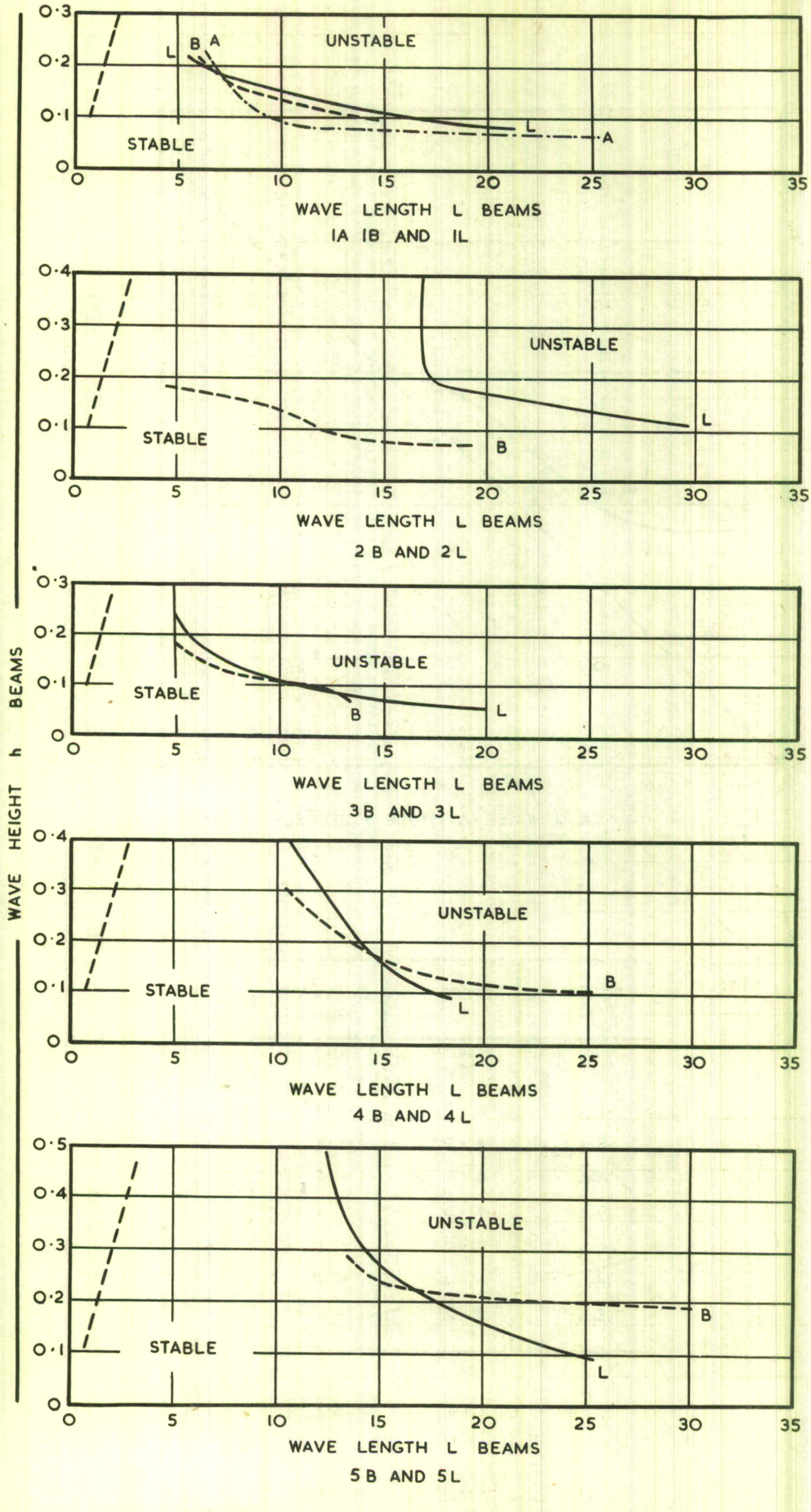
MODEL WAVE DIAGRAMS

FIG.16.



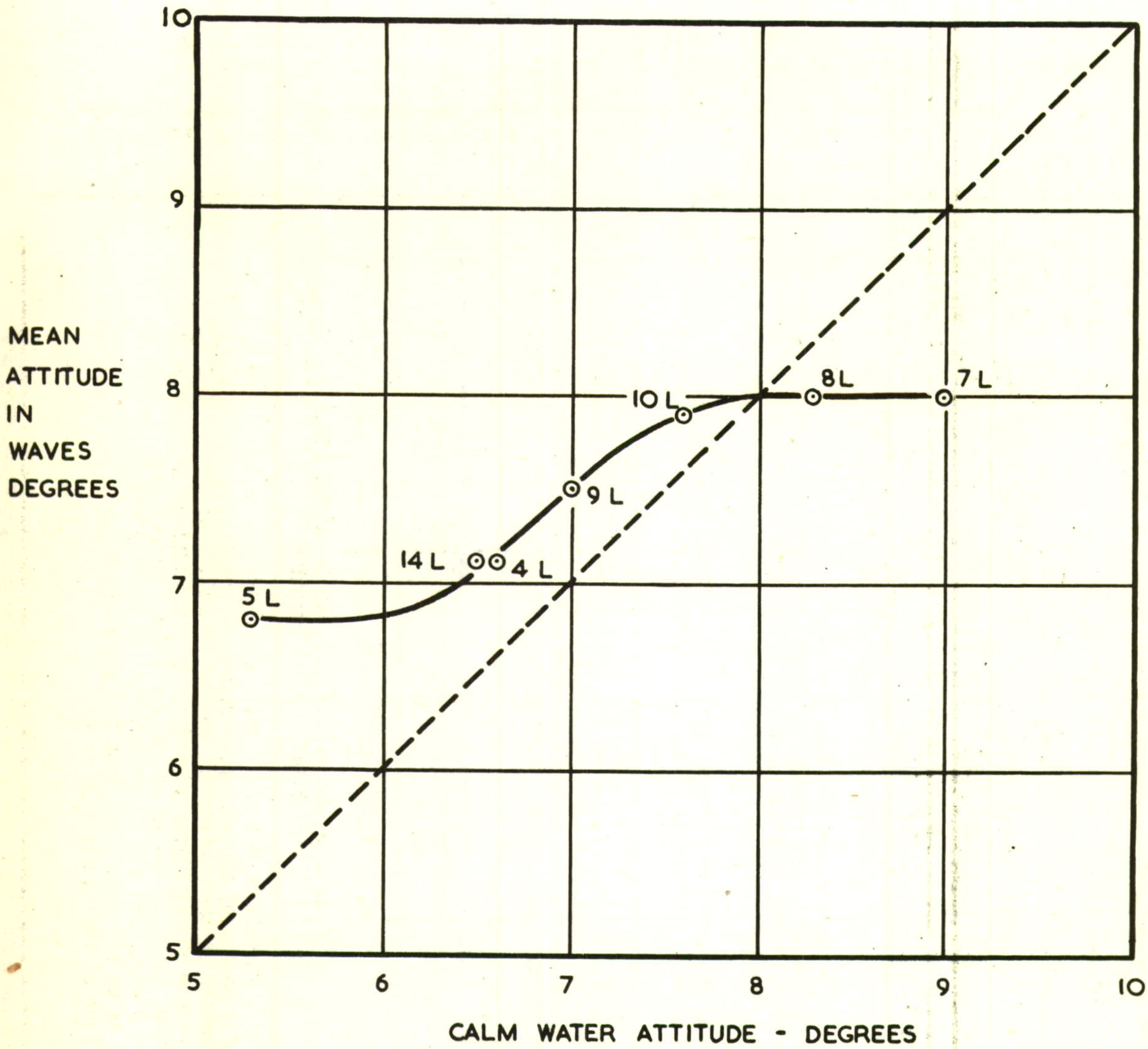
MODEL WAVE DIAGRAMS

FIG. 17.



COMPARISON OF MODEL WAVE DIAGRAMS

FIG. 18.



POINT	SPEED	ELEVATOR ANGLE
	C_V	η
7 L	9 · 2	$-12°$
8 L	8 · 2	$-8°$
10 L	6 · 9	$-4°$
9 L	9 · 2	$-6°$
4 L	8 · 2	$-4°$
14 L	6 · 9	$+4°$
5 L	9 · 2	$-2°$

THE EFFECT OF WAVES ON ATTITUDE

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1955.8.
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INVESTIGATION OF HIGH LENGTH/BEAM RATIO SEAPLANE HULLS WITH HIGH BEAM LOADINGS

HYDRODYNAMIC STABILITY PART 21

SOME NOTES ON THE EFFECT OF WAVES ON LONGITUDINAL STABILITY CHARACTERISTICS

In this report the results are given of tests on three models of the series, designed to provide information on the correlation between stability with disturbance and stability in waves. No correlation was observed, but the results are analysed and compared with previous work, and some important general conclusions are drawn as to the nature of disturbed stability and the behaviour of flying boats in waves.

2.3.1.
2.3.4.
2.3.5.
2.10.1.

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2.3.1.
2.3.4.
2.3.5.
2.10.1.

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